THE
GRAND COULEE

J HARLEN BRETZ

AMERICAN GEOGRAPHICAL SOCIETY
SPECIAL PUBLICATION No.15

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J HARLEN BRETZ

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SPECIAL PUBLICATION NO. 15
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THE GRAND COULEE

BY

J HARLEN BRETZ
The University of Chicago

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THE COMMONWEALTH PRESS, WORCESTER, MASS.

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Reconnaissance topographic and geologic map of Grand Coulee, Washington. Scale 1:253,440 . . . facing p. 86

INTRODUCTION

Grand Coulee is a canyon fifty miles long, nearly a thousand feet deep and about a mile in minimum width. It is now streamless. Trending nearly north-south, it crosses the highest portion of the Columbia Plateau in Washington, an interfluve area fifteen hundred feet above the Columbia River which is itself entrenched at the coulee head along the plateau's northern margin. Its grim black walls of basalt frown across a broken chain of linear lakes, some of them as wide as the coulee floor. This floor is diversified with extraordinary stream-channel features. Here are potholes a hundred feet deep in rock, dry cataracts one hundred to four hundred feet high, and river bars one hundred to two hundred feet thick. Yet many of the lakes are ephemeral or alkaline, the cataracts are merely dry cliffs, and the river bars are hills on the abandoned great stream bed. Permanent streams have almost completely disappeared from the region. Glacial ice caused the drainage detour across the divide and the making of this great trench. On the reopening of the old drainage ways temporarily occupied by ice the coulee became dry, and under the present semiarid climate it lies naked of forest mantle, every detail of its form clearly displayed.

At some time far in the future Niagara Falls will recede through the escarpment which gives it origin, lengthening its gorge as it recedes; and the Lake Erie basin will by this event become dry. Suppose that this had already occurred before the first intelligent observers entered the region. They would find, in place of Lake Erie, a low smooth plain traversed by an eastward-flowing river. Between the Erie and Ontario basins they would find a higher area, the escarpment, trenched by a gorge 300 feet in maximum depth. The hypothesis of a former lake basin would be proposed and, supported by the existence of lake clays and of fragmentary old shore lines, would soon become accepted doctrine. But would the vanished cataract of Niagara be built into the picture?

After a receding cataract has destroyed itself, what features of the gorge it made will record its former existence? Can we distinguish gorges deepened simultaneously throughout their length from gorges cut by a mechanism like a huge power shovel which advances into unchanneled territory and leaves a fully dug trench behind it? This is the gist of the problem of Grand Coulee. We have Niagara and the Victoria Falls in action to guide us and can grant the possibility of former falls of their magnitude. But can we think favorably of a vanished cataract more than seven times the width of Niagara and more than five times its height?

CHAPTER I

GENERAL FEATURES OF GRAND COULEE

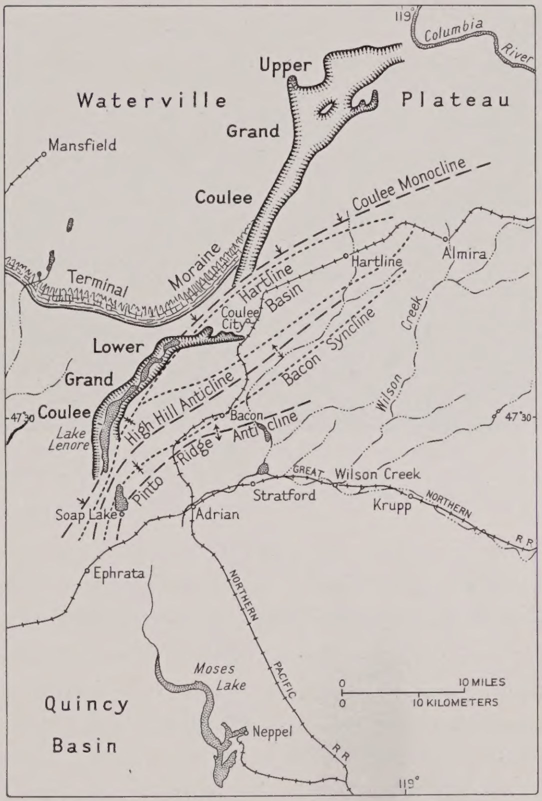
119°
Columbia River
Upper
Waterville
Plateau
Grand
Mansfield
Coulee
Coulee Monocline
Almira
Hartline
Terminal Moraine
Hartline Basin
Coulee City
Bacon Syncline
Creek
Lower
Grand
Coulee
47°30
Lake Lenore
High Hill Anticline
Bacon
Bacon Anticline
Wilson
47°30
Pinto Ridge
Great Wilson Creek
Stratford
Krupp
Northern
R R
Soap Lake
Adrian
Ephrata
Northern Pacific R R
Moses Lake
0 10 MILES
0 10 KILOMETERS
Quincy Basin
Neppel
119°

Fig. 1—Sketch map of salient features of the Grand Coulee region.

The landscape of the Columbia Plateau of eastern Washington consists on the whole of softly molded rolling hills and valleys, carved with almost monotonous regularity out of a great plane substratum. The dominant type of landscape is interrupted by a few notable canyons, the extraordinary network of elongated scabland tracts,[1] and by warpings of the basalt sheet itself. The greatest of these conspicuous warpings is a monoclinal structure extending eastward for a hundred miles across the northwestern part of the plateau. Topography faithfully portrays the structure; a steep slope descending several hundred feet toward the south and southeast all along its course. The higher tract northwest of the flexure is the Waterville Plateau, the low tract to the southward is the Quincy Basin. The basalt sheets under the higher tract are nearly horizontal, but on the downward side of the monocline they have a variable dip as shown in Figure 1.

---

[1] Scabland is the appropriately descriptive local term for the surfaces with little or no soil above the basalt bed rock. See the author's article, "The Channeled Scabland of Eastern Washington," *Geogr. Rev.*, Vol. 18, 1928, pp. 446–477.

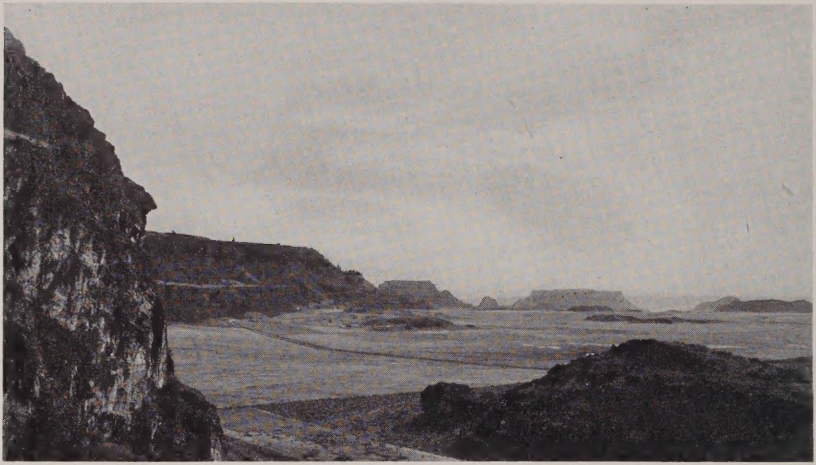

FIG. 2—Rock hills on the floor of upper Grand Coulee; view looking southwest. The two flat-topped hills are of basalt, the rounded ones are of granite, the smooth floor is a plain of silt. The largest hill is Steamboat Rock. (Photograph by Curtis.)

The structure is really an asymmetrical anticline whose southeastern limb, the "monocline," is much longer and descends to much lower surfaces than the northwestern limb. In some places the anticlinal crest is absent, and it is a true monocline. In other places the structure possesses two or three smaller asymmetrical corrugations along the down-dip side.

Grand Coulee is intimately related to this monocline. It really consists of two canyons, the upper one leading southward for twenty-five miles from the deep Columbia Valley across the Waterville Plateau to the monocline, the lower or southern one being a seventeen-mile trench with a gap of six miles between it and the northern canyon. Here the basalt cliffs disappear as the monocline is crossed and the old watercourse spreads out on the floor of a minor structural basin. Six miles farther south, the coulee returns to the monocline (see Fig. 1) and again becomes a great canyon, continuing so for seventeen miles. Twelve miles of this lower coulee is cut in tilted flows. This makes its western wall about twice as high as the eastern wall. Southward from the terminus of the lower canyon the old watercourse leaves the monocline completely and loses its erosional character. It becomes a broad plain of cobbly gravel extending for thirty miles across the Quincy Basin.

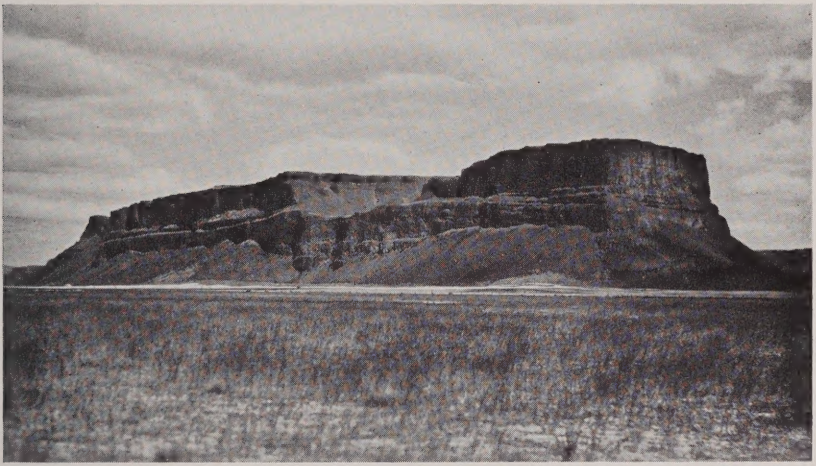

FIG. 3—Northwest side of Steamboat Rock. The cliff possesses a hanging valley niche, identical with those margining the upper coulee where summit scabland occurs on each side. It was not made by postglacial drainage from the summit, nor can the valley be interpreted as a preglacial valley and the Rock as a preglacial divide. The channel enters *from the air* on the eastern side. (Photograph by Simmer.)

THE UPPER COULEE

The head of Grand Coulee, in the southern slope of Columbia Valley, is simply a great notch cut about two-thirds as deep as the master valley. The rock floor in the coulee head has an altitude of 1500 to 1550 feet above sea level. Although the coulee bottom southward for twenty-five miles is considerably diversified with knobs of rock, terraces, basins, etc., the average altitude of the bottom portions remains very close to this same figure. The first extraordinary item regarding the upper canyon of Grand Coulee is the absence of a continuous gradient, despite the abundant evidences of torrential stream action.

The depth of the upper canyon is everywhere 800 to 900 feet. In most of its course it is enclosed between unbroken vertical walls whose summits are nearly the same elevation, 2300 to 2400 feet above sea level. This is the elevation of the plateau surface, and the extraordinary fact is at once realized that there is no gradient to the plateau across which the canyon was cut.

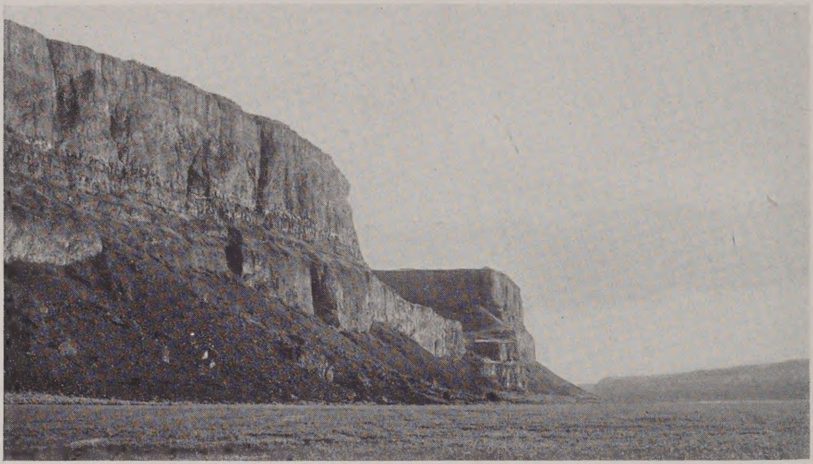

FIG. 4—Lateral or tributary canyon, upper Grand Coulee; view looking southwest along the eastern wall, about 15 miles north of Coulee City. The proportions of the amphitheater back of this notch are shown in Figure 30. The cultivated silt floor of the coulee lies at the foot of the cliff. (Photograph by Curtis.)

The floor in the northern part of the upper coulee is interrupted by numerous rock hills, some of which rise nearly or quite as high as the enclosing walls and are equally steep. Steamboat Rock (see Pl. I and Figs. 2 and 3) is the largest and highest. A definite row of these hills crosses the coulee a little north of this rock, and most of the notches separating them come down to the coulee floor. Measured two hundred feet above the floor, these hills constitute about two-fifths of the coulee width. The existence of these separated hills on the canyon floor is another extraordinary feature of the canyon of upper Grand Coulee.

Except for the southernmost ten miles of the western cliff, all of the summits of the margining cliffs carry a very rough bare basalt surface which extends back from the edge for an average distance of two miles and a maximum of at least four miles. On the east, this scarified surface of low buttes and shallow rock basins terminates against higher land at about 2400 feet above sea level, and above it lie soil-covered mature slopes dissected in dendritic patterns by local run-off. It is stream-bottom topography, similar to hundreds of other square miles of scabland network cut into the plateau surface. A glacial river surely swept this tract before the deep canyon was cut, and that river had a maximum width certainly as much as ten miles. In this record of a very wide stream above the cliff summits Grand Coulee departs greatly from ordinary canyons.

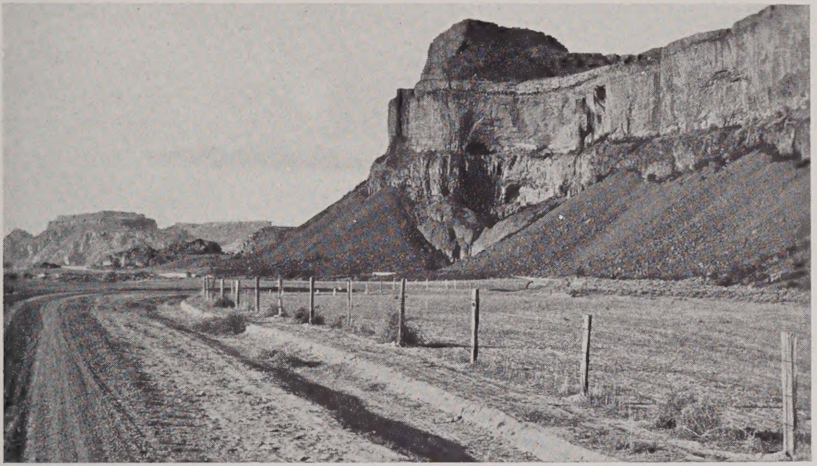

Fig. 5—Mouth of hanging lateral canyon, upper Grand Coulee; view looking north along the eastern wall. The full height of the wall is not shown. A storm-water cataract (Martin Falls) descends this cliff in springtime. Silt floor in the foreground. The distant buttes are between Grand Coulee and Northrup Canyon. Compare Figure 32. (Photograph by Simmer.)

Northrup Canyon

We shall now examine the tributaries to upper Grand Coulee in relation to the scabland topography. Only a few wet-weather streams flow into the canyon, and, except at the extreme northern end, tributary waters with their débris enter the ephemeral and the alkaline lakes. The largest tributary is Northrup Canyon (see Pl. I). It is most peculiarly oriented for a tributary. If one follows up either of the two heads of Northrup, one finds oneself led back almost to the brink of the coulee. One finds also that the blunt heads are great cliffed amphitheaters with high vertical walls, wholly unlike the heads of normal drainage valleys above the level of the upper scabland. Northrup Creek on entering Grand Coulee flows northward, against the course of the glacial river that occupied Grand Coulee, and discharges into Devils Lake between two high rock hills in the row above referred to. The lake occupies a quarter of a section, about one-fifteenth of the area covered by the tributary canyon. That this lake basin contains the débris eroded in making Northrup Canyon is an impossible theory; and there is no fan or delta deposit that might contain any considerable part of it.

Other tributaries resemble Northrup in being blunt-headed, vertically-cliffed amphitheaters; but most of them are so short that they are essentially great niches in the coulee wall. The floors of some hang above the coulee floor, halfway up the 800-to-900-foot cliff or even higher, and their storm waters make cataracts on entering the coulee (see Figs. 4 and 5). Surely none of these are normal tributaries developed since the glacial river ceased to flow. Surely none are normal tributaries of a valley that antedated the glacial stream erosion. There are, however, some normally shaped tributaries in the upper coulee. They are limited to the ten-mile stretch along the western wall without summit scabland (Fig. 6). No cirque-like tributary niches or gashes occur here; they are all on the walls with scabland summits.

A final feature of upper Grand Coulee should now be noted. The dotted line on Plate I is the 1530-foot contour. Except for a trench only 175 feet wide across the rock floor at the south end of the upper coulee, the area enclosed by this contour is a closed basin. Yet it covers a third of the coulee floor and over large areas is thirty to forty feet below the 1530-foot contour. The narrow trench never carried any considerable part of the débris that would come from excavating this basin. Most of the débris must have been carried upgrade to get out. Wells in the bottom flats of the coulee

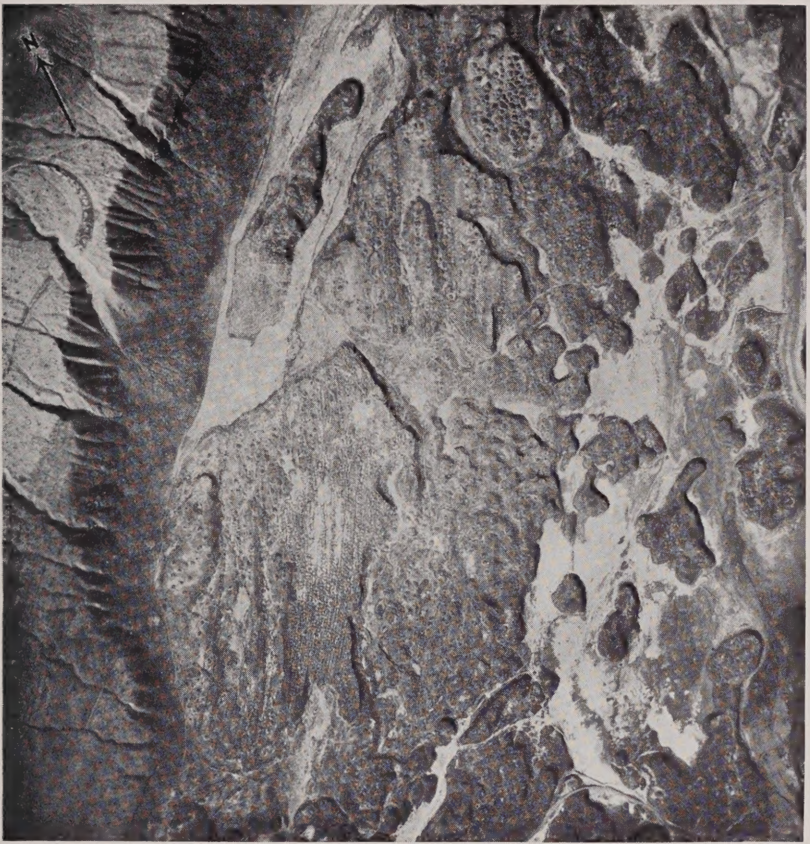

FIG. 6—Scabland floor of Grand Coulee in Hartline Basin; the southern end of the western wall shows along the left edge of the picture. Above it are normal erosional gullies, hanging far above the scabland channel floor. The relief among these channel buttes and basins is more than 50 feet.
This and all the other vertical aerial photographs were taken at an altitude of about 11,000 feet. (Grand Coulee Series, 33, U. S. Geological Survey.)

have found only silt, sand, gravel, and boulders, although they have gone down to 1313 feet above sea level. The rock basin of upper Grand Coulee is more than five times as deep as the topographic basin. Yet there is a rock floor at each end higher than the surface of the basin fill between.

THE HARTLINE BASIN

Five or six miles southeast of the Coulee monocline and subparallel with it is High Hill anticline, considerably less

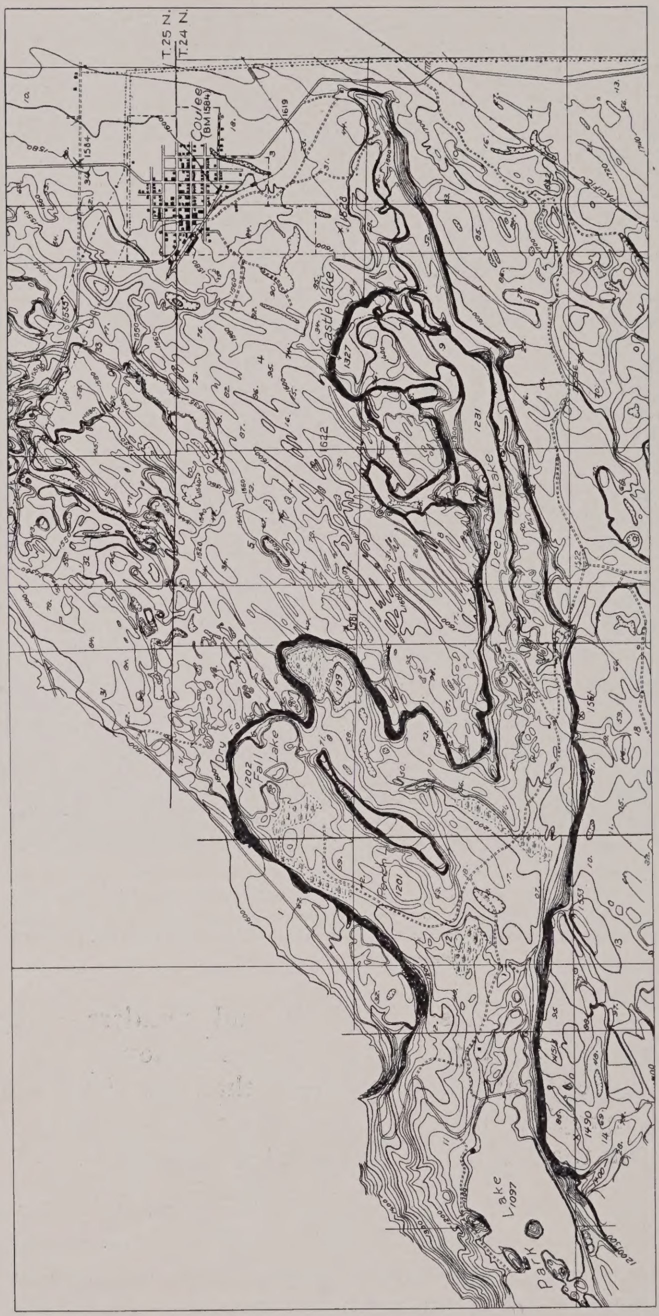
T.25 N.
T.24 N.
Coulee
BM 1584
1584
1619
Castle Lake
1327
1622
Deep Lake
1231
1197
Dry Falls
Fall Lake
1202
1201
1561
1490
Park
Lake
1097

FIG. 7—The great cataract group in Hartline Basin. Contour interval 20 feet in T. 24 N.; in T. 25 N. it is 5 and 20 feet, changing on the 1560 contour. Reduction of a part of Sheet 4, Grand Coulee topographic map, U. S. Geological Survey; scale approximately 1 inch to the mile.

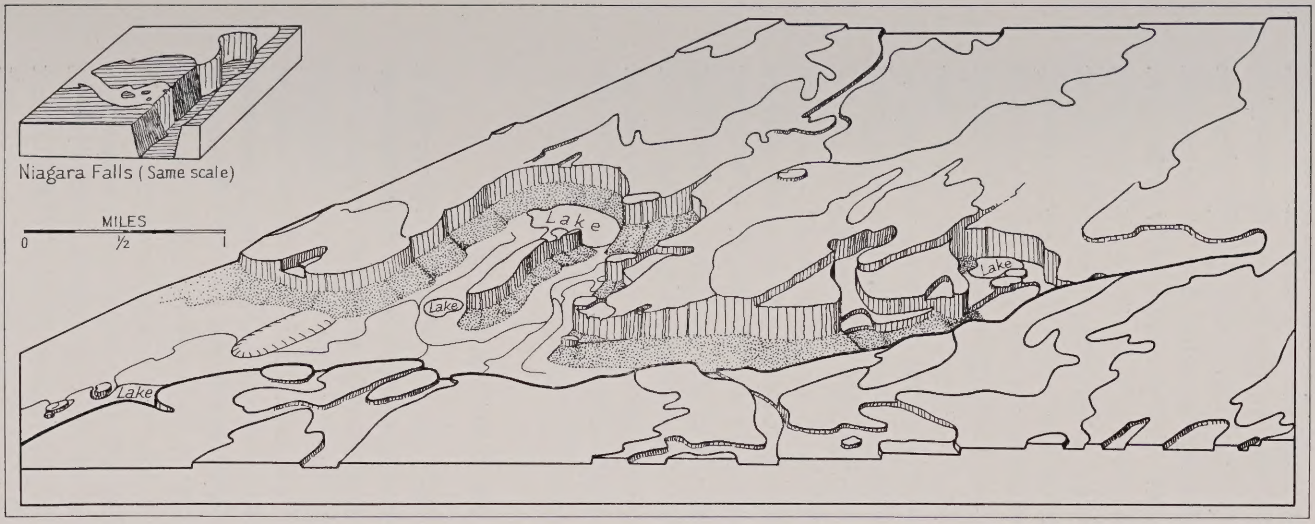
Niagara Falls (Same scale)
MILES
0
½
1
Lake
Lake
Lake
Lake

FIG. 8

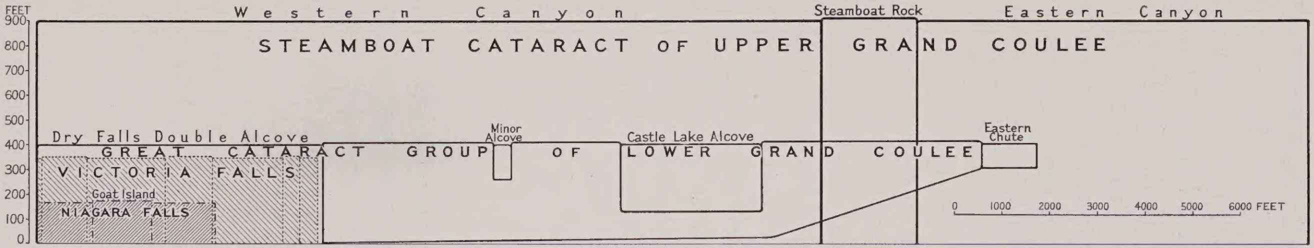
FEET
900
800
700
600
500
400
300
200
100
0
Western Canyon
Steamboat Rock
Eastern Canyon
STEAMBOAT CATARACT OF UPPER GRAND COULEE
Dry Falls Double Alcove
Minor Alcove
Castle Lake Alcove
Eastern Chute
GREAT CATARACT GROUP OF LOWER GRAND COULEE
VICTORIA FALLS
Goat Island
NIAGARA FALLS
0 1000 2000 3000 4000 5000 6000 FEET

FIG. 9

FIG. 8—Block diagram of the great cataract group, looking north. Compare with the topographic map (Fig. 7) and the photographs (Figs. 10, 45, and 50). The walls of Niagara Falls and gorge, having no talus, appear higher proportionately than those of the cataract group with talus halfway up the original cliffs.

FIG. 9—Diagram of the two great cataracts of Grand Coulee compared with Niagara and the Victoria Falls.

prominent topographically than the coulee fold. Between these is a minor structural valley in the basalt, the Hartline Basin, about twenty-four miles long. The glacial river on descending the monoclinal slope entered the southwestern end of this basin and spread widely over nearly half of it. There seems to have been relatively little erosion into the basalt as the stream crossed the basin floor, probably no more than a hundred feet. Most of the basin is deeply aggraded, but in the main path of the torrent its rock floor was laid bare and is remarkably scarred with butte, basin, and channel features characteristic of large streams flowing across flat-lying Columbia basalt flows (Fig. 6 and upper part of Fig. 7).

The glacial water escaped from the Hartline structural basin over the southern rim, greatly eroding about twelve miles of the crest of High Hill. Five marked canyons down the southeastern slope of this structural-topographic feature lead out from the flooded area of Hartline Basin. The heads of all of them had receded across the anticline before they were abandoned, and two of them became incised to a level lower than the bare rock floor in the main path of the river. One of these, the westernmost of the group, is part of the course of lower Grand Coulee.

Dry Cataracts of the Lower Coulee

Lower Grand Coulee heads in the Hartline Basin as a magnificent group of huge dry cataracts, three and a quarter miles across and four hundred feet in maximum height. As shown in Figures 7 and 8, there are at least five different recesses in the cliff line of these falls. It is difficult to believe that they were developed successively. None is of the type which the American Falls of Niagara are fated to become—a lateral subsidiary cataract abandoned because of greater recession of the major fall. One of the recession alcoves, in mid-channel, was retreating in a tract about eighty feet higher than that at the head of the largest alcove, yet it was subsidiary to a larger fall with lower brink. The largest alcove, made by a double fall, Dry Falls, has the lowest brink of all, lies in the most direct channel route and nearest to the point above which all these alcoves and gorges have separated, yet it has receded the minimum distance from that point. If the falls have differences in age, it seems probable that the eastern part of the group became abandoned as a unit because of a notable decrease in volume of the glacial river. Dry Falls, which has the advantage of position and altitude of lip, does not appear to have cut off its rivals' water supply by greater recession, in the fashion forecast for the American Falls when the Canadian Falls have retreated far enough upstream.

The great cataract group is developed in nearly flat-lying flows of the Hartline structural basin (see Fig. 10). Just west of the falls and the rock-floored channel above them the monocline rises for several hundred feet, the river course lying at its foot. It is soil-mantled and furrowed by normal gullies and gulches which mouth not far above the highest rock floor above the cataracts. A scarp a hundred feet or so high marks the western edge of the scabland floor, and the watercourses have trenched its brink and built fans at its foot until their hanging character is largely lost. All this is above the level of cataract lips.

The Cataract Recession Gorge

When traced down-coulee the gorges made by cataract recession in the Hartline Basin floor merge into one about two miles below Dry Falls, and this gorge leads out of the structural valley and into the tilted flows of the monocline margining that basin south of the cataract (Pl. I). Here the coulee is a great gorge again, its western wall having all of a thousand feet of maximum height. But its eastern wall in the southernmost part of the basin floor is only four hundred to five hundred feet high. In a region like the Columbia Plateau in Washington, where original structure is so largely expressed in topography that most drainage is still consequent on the warpings, this is a most curious thing. Avoiding what were originally lower surfaces just to the east, the canyon is located *on and along* what was preglacially a steep slope descending to the structural valley. A remnant of that slope, about five miles long, unmodified by glacial water, characterizes the monocline west of the cataract group. The lower coulee maintains this curious location in the monocline to, and beyond, the southwestern end of Hartline Basin. Furthermore, the canyon here is no wider than the belt of flexed and broken basalt. The flows in both walls are horizontal or show only slight bending. Hogback islands in the lakes record the tilted structure, as also does a section at the head of Park Lake where the cataract gorges unite and enter the monoclinal zone. In this section (Fig. 11) the steepest flows stand about sixty degrees to the horizon.

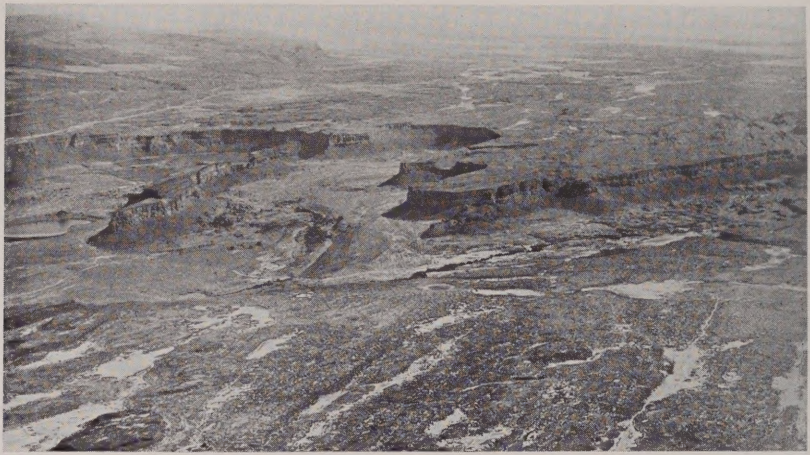

FIG. 10—The great cataract group, western part, looking north. The double alcove of Dry Falls and the long alcove containing Deep Lake are in the middle distance, and the channeled scabland floor of Hartline Basin lies farther north. In the immediate foreground is more of this channel floor, abandoned when the cataract receded through it. Compare Figure 45, and note especially the "Goat Island" partially separating the two Dry Falls alcoves. (Oblique aerial photograph by Libby & Son.)

At the southwestern end of the Hartline Basin, as delineated on Figure 1, the space between the coulee monocline and High Hill anticline is a synclinal valley, actually of course the same structure that makes Hartline Basin but much narrower. For eight miles, the length of Lake Lenore, the lower coulee canyon continues along this feature; but, as before, it is not in the syncline, as a consequent drainage way should be. It is eroded in and along the hillside afforded by the monoclinal descent of the plateau surface and is limited, as above noted, to the belt of bent and broken flows (Fig. 41).

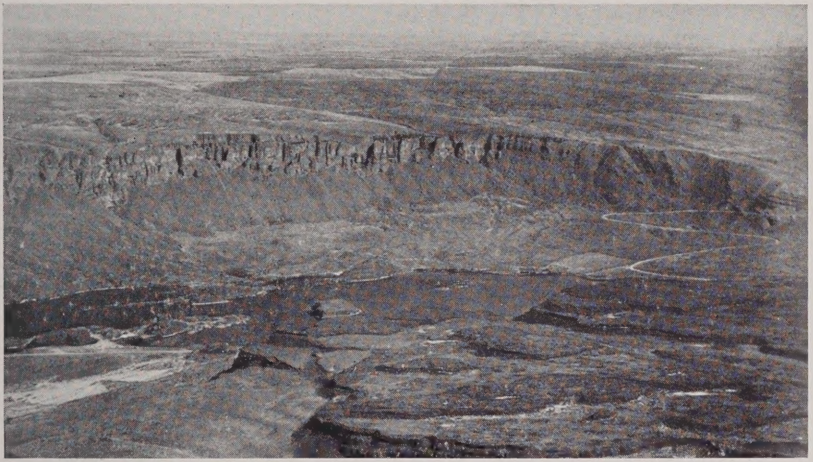

FIG. 11—Park Lake, lower Grand Coulee, looking north. The plateau above the western cliffs stretches back to the horizon. Note its normal erosional forms, out of adjustment with the coulee. The monoclinal slope and structure both show above the serpentine of the road. Scabland summits above the eastern cliff in the foreground. (Aerial photograph by Libby & Son.)

All told, more than twelve miles of lower Grand Coulee is eroded in the monocline. A little beyond the southern end of Lake Lenore the coulee and monocline part company, the coulee swinging somewhat eastward to cross High Hill anticline, Bacon syncline, and Pinto Ridge anticline—all within a distance of four or five miles. These corrugations are structurally and topographically inferior to the coulee flexure, but they exercised a marked control of preglacial and glacial drainage.

CONTRASTS BETWEEN WESTERN AND EASTERN WALLS

The summit of the western wall of the southern coulee rises from seven hundred to at least a thousand feet above the lakes on its floor. It is everywhere notched by hanging valleys, the original lower portions of which have been entirely destroyed in making the canyon. None of them mouth more

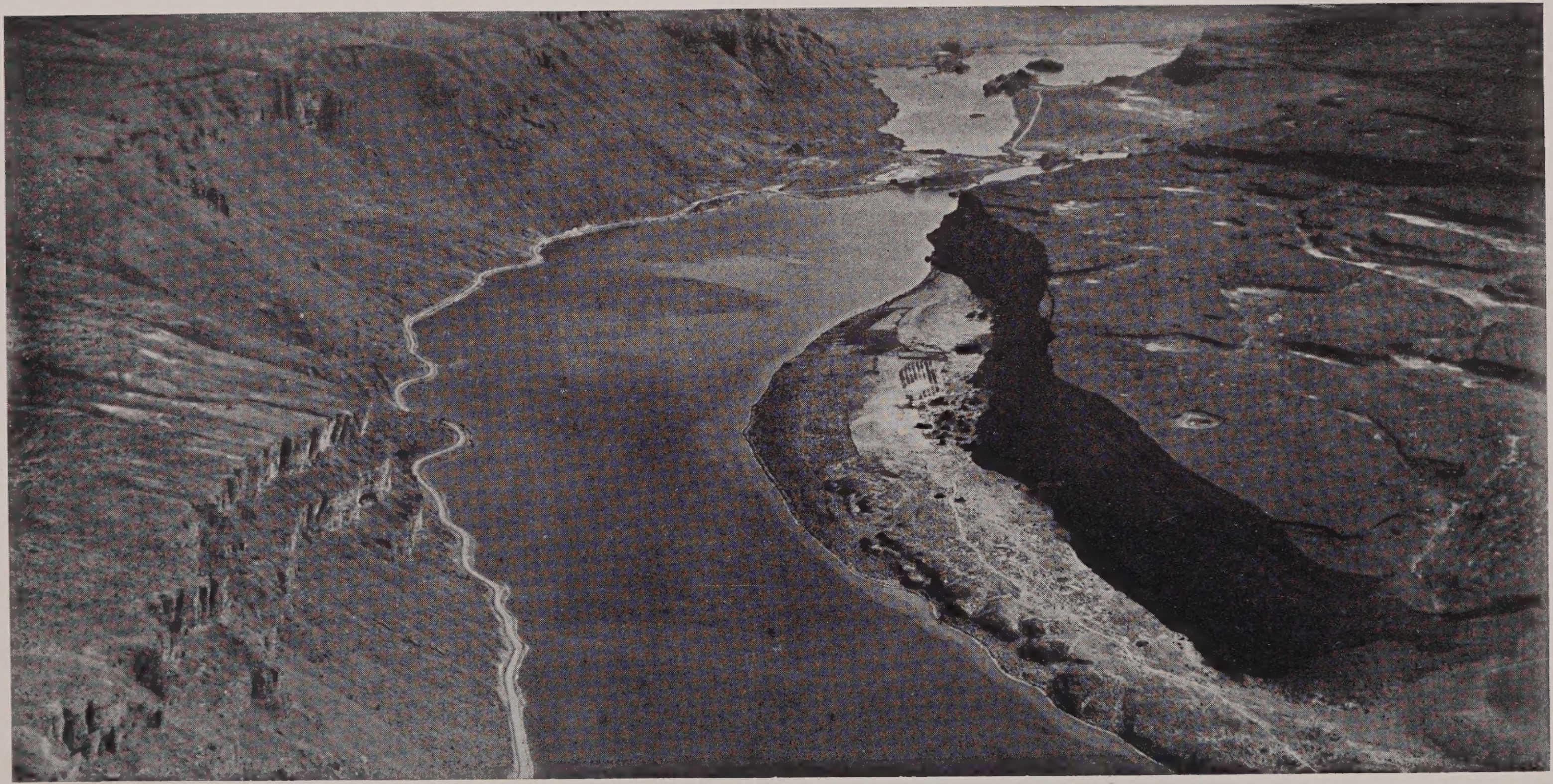

FIG. 12—Blue Lake, lower Grand Coulee, looking northeast. The normal drainage forms on the summit of the western cliff are 900 feet or so above the lake, and the channeled scabland above the eastern cliff is 400 feet higher than the lake. The maximum known depth of the lake is 60 feet. In two places the western cliff shows the beginning of the monoclinal descent. (Oblique aerial photograph by Libby & Son.)

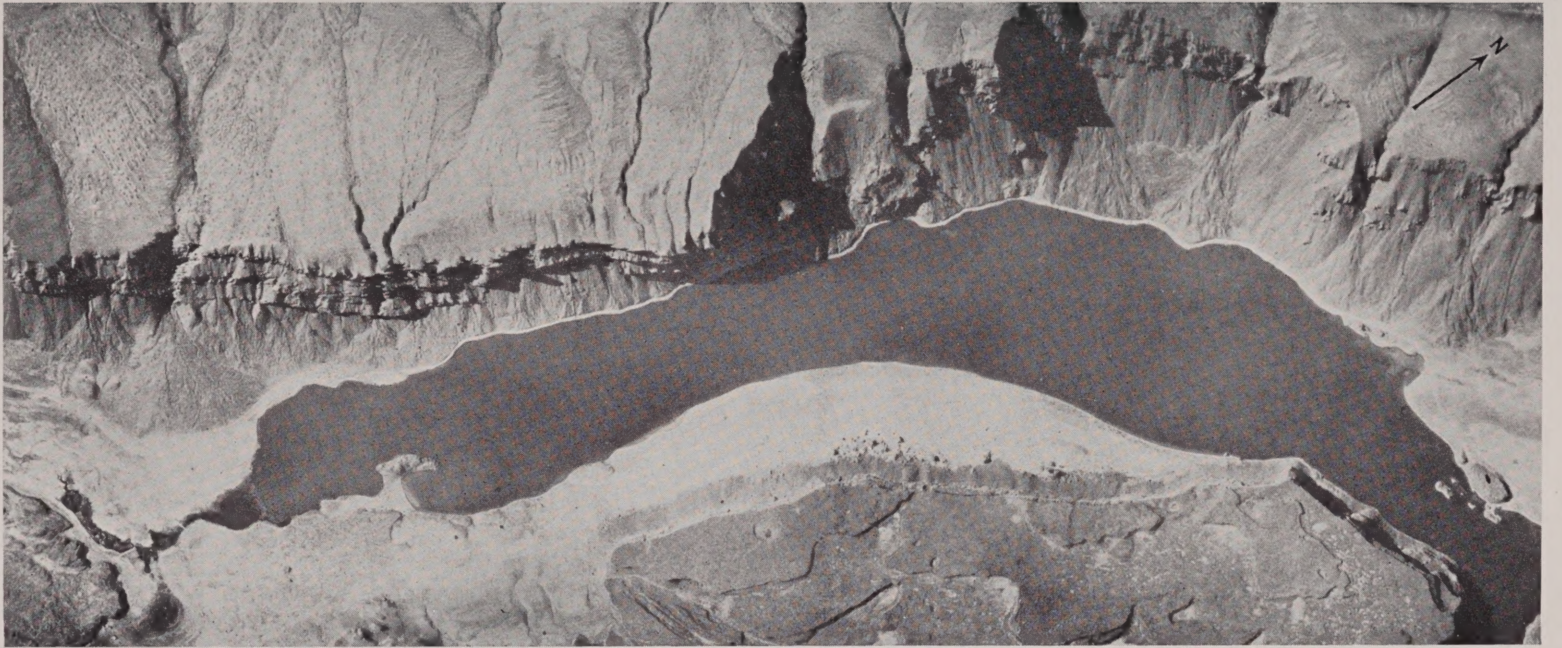

FIG. 13—Blue Lake, lower Grand Coulee. Hanging tributaries of the preglacial drainage notch the brink of the high western cliff. Butte-and-basin scabland covers the summit back from the lower eastern cliff. The head of Jasper Canyon, containing a bay of the lake, shows at the extreme eastern corner. The light-hued tract between the lake and the eastern cliffs is a partly submerged bar on the floor of the glacial river channel. The lake occupies the monoclinal belt. (Mosaic of vertical aerial photographs, Grand Coulee Series, 15–19, U. S. Geological Survey.)

than a third of the way down the cliff face, and most of them make only minor notches in the cliff summits. Figure 13 shows the normal character of these small streamways and their hanging relation to the canyon. They show also in several other views of the lower coulee. They are of the same genesis and same age as those that descend all the way to the highest channel floor west of the cataract group. When they were formed, there was no canyon along the monocline.

In contrast with the summit of the western wall, the top of the much lower eastern wall along Lake Lenore is marked scabland. Rock basins as much as a hundred feet deep occur on it, buttes and blades as much as two hundred feet above their surroundings, canyon-like trenches with vertical walls uniting and dividing in the fashion known all over the plateau scabland, dry cataract cliffs a hundred feet high, and dry plunge pools at their bases—all channel-bottom features of an extraordinary glacial stream. Some of these features occur three hundred to five hundred feet above the lake. And here, in this eastern summit scabland of lower Grand Coulee, lies the axial line of the syncline that was deserted by the glacial river for the parallel monoclinal course only a mile distant. The monocline clearly is but the northwestern limb of the structural-topographic syncline. Whatever the cause of the drainage adjustment here, it shifted the course laterally over into the hillside and left the synclinal floor, though greatly scarred by a great stream, standing two hundred to five hundred feet above the bottom of the new route. Throughout this tract all scabland surfaces are channel features.

The coulee walls are much lower south of Lake Lenore. Soap Lake, in the mouth of the coulee, appears to lie in Bacon syncline. The cliffs west of the lake are eroded in High Hill anticline, those to the east apparently are developed in Pinto Ridge anticline. A carefully constructed topographic map of the region would show more significant structural shapes in the hills east of the lower coulee. It would also show a diversity of drainage furrows. Only two of the canyons associated with the eastern hills are known to be anticlinal crossings. The others, although deepened by erosion, may be sags in anticlinal axes or gaps between localized short anticlines.

MOUTH OF THE GRAND COULEE

Like upper Grand Coulee, the lower coulee has essentially no gradient and is a closed basin. There is a descent of 105 feet from Fall Lake, in the westernmost alcove of the great cataract group, to Park Lake, a distance of two miles. But thence to Soap Lake, fifteen miles farther, the fall is only a few feet. Park and Blue lakes are fresh, but Lenore and Soap lakes are alkaline, the latter with twenty-eight parts of mineral matter per thousand. South of Soap Lake is the gravel plain of Quincy Basin. Near Ephrata the surface of this plain is nearly 250 feet above Soap Lake and more than 130 feet above Fall Lake. There is a fairly smooth upward slope southward (downstream!) all the way from Soap Lake to Ephrata, averaging 140 feet per mile. It is distinctly not a terraced slope. Nor are terraces recognizable in the twenty-four gravel-buried townships of Quincy Basin except along the one valley, Moses Lake Valley, that crosses it. This great gravel deposit at the mouth of Grand Coulee has been interpreted as an accumulation of huge river bars. Topography, space relations, and structure demand this interpretation though its application to the northward slope toward Soap Lake requires an extraordinarily large glacial river.

Unlike the upper section of Grand Coulee the lower section has preglacial hanging tributary valleys along its entire west side and essentially no tributaries along the east side, either in the form of normal gullies or the amphitheater-headed type of the upper coulee. Instead, there is presented the surprising phenomenon of two pronounced distributary canyons which join and lead over to Dry Coulee. Both canyons are clogged with bar gravel, the shapes of the bars and their locations with respect to rock shoulders and knobs indicating the direction of flow of the waters once occupying them.

SUMMARY OF ABERRANT FEATURES

The many aberrant features of Grand Coulee must signify some extraordinary conditions of origin.

1. The upper coulee is a twenty-five-mile gash, vertically walled, 800 to 900 feet deep, across horizontal flows of the highest part of the plateau.

2. The lower coulee is a seventeen-mile canyon, nearly thirteen miles of it eroded in and along the preglacial structural hillside of the coulee monocline.

3. The two canyoned portions are separated by a five-mile uncanyoned portion on the floor of Hartline structural basin.

4. A group of immense cataracts is entrenched in the Hartline Basin. Had they receded five miles farther, the coulee would have been one continuous canyon.

5. The mouth of the lower coulee in the Quincy structural-topographic basin is blocked by huge gravel deposits.

6. Both canyoned portions have essentially no gradient.

7. The floors of both canyoned portions are closed basins.

8. The floor near the head of the upper coulee is interrupted by numerous high hills of rock.

9. Stream-channeled basalt surfaces occur on top of the walls of the upper coulee for four-fifths of the total wall length. Their maximum width is four miles.

10. The summit of the eastern wall of the lower coulee, 400 to 500 feet high, is all channeled scabland. The summit of the western wall, 700 to 1000 feet high, has no scabland.

11. Minor tributary valleys produced by local run-off enter the coulee only where there is no summit scabland. They hang far up on the cliffs, except in the structural valley between the two canyoned portions.

12. Tributaries from scabland summits along the upper coulee have striking amphitheater-like shapes. Many have a hanging relationship, others enter the coulee at grade.

13. Lower Grand Coulee has essentially no tributaries from its margining high scabland but possesses two notable canyoned distributaries.

CHAPTER II

THE DISTRIBUTARY SYSTEM OF GRAND COULEE

The two canyons of Grand Coulee constitute only a part of the record of glacial water that once flowed across the plateau (see Fig. 14). Another great canyoned course (Moses Coulee) lies about fifteen miles farther west, comparable in many ways to Grand Coulee, though it is not trenched across the divide. Two large and complex groups of spillways lie to the east, between Grand Coulee and Spokane, each with a multitude of islands of pre-scabland mature topography separated by a maze of scabland channels. Neither of these spillway groups is canyoned across the divide. The opportunity for canyoning in Moses and Grand coulees was afforded by the steep monoclinal slope down which they spilled. Upper limits of scabland in all four of these spillways lie within a vertical range of about two hundred feet, but the bottom of upper Grand Coulee, when the canyoning ceased, was a thousand feet lower than any other spillway floor across the divide.

Grand Coulee is not simply a tandem canyon. From Hartline Basin southward the country to the east was overrun by water escaping from the Grand Coulee. Great changes were wrought by this water as far as twelve miles east of the lower coulee. Across the fold-determined topography east of the monocline, Grand Coulee water entered Quincy Basin by three more routes: Dry Coulee, Spring Coulee, and an unnamed minor spillway eighteen miles east of the main route. The two last-named routes really entered the Crab Creek glacial river, itself a contributor to Quincy Basin though carrying a smaller volume than the Grand Coulee discharge.

Except for a relatively insignificant spill from Wilson Creek glacial river over into the extreme eastern end of Hartline Basin, all of this extensive distributary group of channels was operated by Grand Coulee overflow. The first overflow

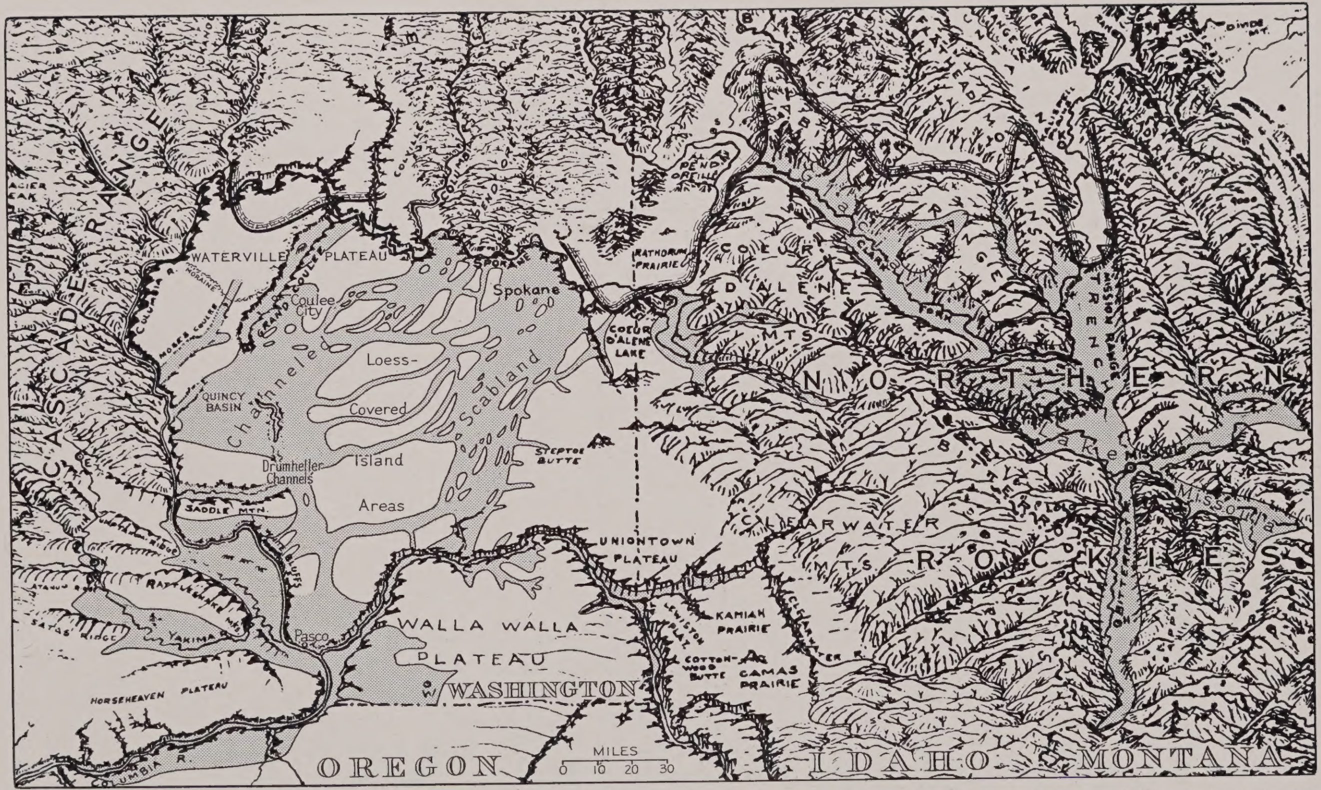
CASCADE RANGE
WATERVILLE PLATEAU
MOSES COULEE
MORAINE
COLUMBIA R.
GRAND COULEE
Coulee City
QUINCY BASIN
Channeled Scabland
Loess-Covered Island Areas
Drumheller Channels
SADDLE MTN.
BLUFFS
RATTLESNAKE HILLS
YAKIMA
SATUS RIDGE
HORSEHEAVEN PLATEAU
Pasco
Spokane
SPOKANE R.
STEPTOE BUTTE
RATHDRUM PRAIRIE
PEND OREILLE
COEUR D'ALENE LAKE
COEUR D'ALENE MTS
CLARK FORK
MISSION RANGE TRENCH
Missoula
UNIONTOWN PLATEAU
WALLA WALLA PLATEAU
LEWISTON PLAT.
KAMIAH PRAIRIE
COTTONWOOD BUTTE
CAMAS PRAIRIE
CLEARWATER MTS
CLEARWATER R.
BITTER ROOT
NORTHERN ROCKIES
DIVIDE MT.
WASHINGTON
OREGON
IDAHO
MONTANA
MILES
0 10 20 30

FIG. 14—Diagrammatic representation of the channeled scabland of the Columbia Plateau and of the glacial lakes Coeur d'Alene and Missoula in the Rocky Mountains. The highest records of glacial Lake Missoula are 4200 feet above sea level, and of glacial Lake Coeur d'Alene are 2691 feet; channel heads along the northern edge of the plateau range from 2400 to 2500 feet, and highest records of glacial water there are 2550 feet above sea level. Failure of the ice dam for glacial Lake Missoula at Lake Pend Oreille would allow about four-fifths of the total impounded waters to escape southwestward, if no glacial ice obstructed the valley at Rathdrum Prairie. If an ice dam then existed in the Columbia west of Grand Coulee, this water must have escaped across the plateau along the scabland routes. (Modified from Lobeck's Physiographic Diagram of the United States, 1922.)

occurred on the monoclinal slope itself at the mouth of the upper coulee. Plate I shows two scarps here, one above the other, with a scabland tract on the semi-terrace separating them. The semi-terrace and lower scarp constitute a fairly prominent rock shoulder. The scarp, where it faces the coulee, is basalt; but the flows here dip forty-five degrees to the southeast and disappear in that direction beneath a heavy cover of gravel which constitutes the scarp south of the salient. Above the greatly eroded top of the salient the slopes are without scabland. Figure 15 shows most of this tract. A part of the glacial river certainly crossed this summit.

The Hartline Basin Gravel

The broadest overflow from Grand Coulee occurred in Hartline Basin and is recorded by a continuous sheet of basalt gravel over about seventeen square miles immediately east of the coulee. The gravel plain is two hundred to three hundred feet above the butte-and-basin floor north of the cataracts. The relatively gentle scarp descending from the plain to the bare rock floor may be erosional in origin, but it carries no definite terraces or furrowed crenulations to record that origin. Its smooth surface resembles the back slope of the Quincy Basin gravel descending northward to Soap Lake. The gravel certainly came out of Grand Coulee. Foreset beds are present in every exposure of its structure and in most of them foreset bedding is the only structure. The dip is in every case eastward, away from the coulee. This is true despite the fact that the surface of the gravel plain slopes gently down in the opposite direction, away from High Hill anticline and toward the mouth of the upper coulee. The foreset beds here dip against the regional slope but in the direction which the glacial water had to flow in order to erode the canyons across and down the south slope of the anticline.

Such relations as these require that the gravel plain be interpreted as a stream-bottom feature. It was not formed in the manner of flood plains, delta plains, valley trains, out-

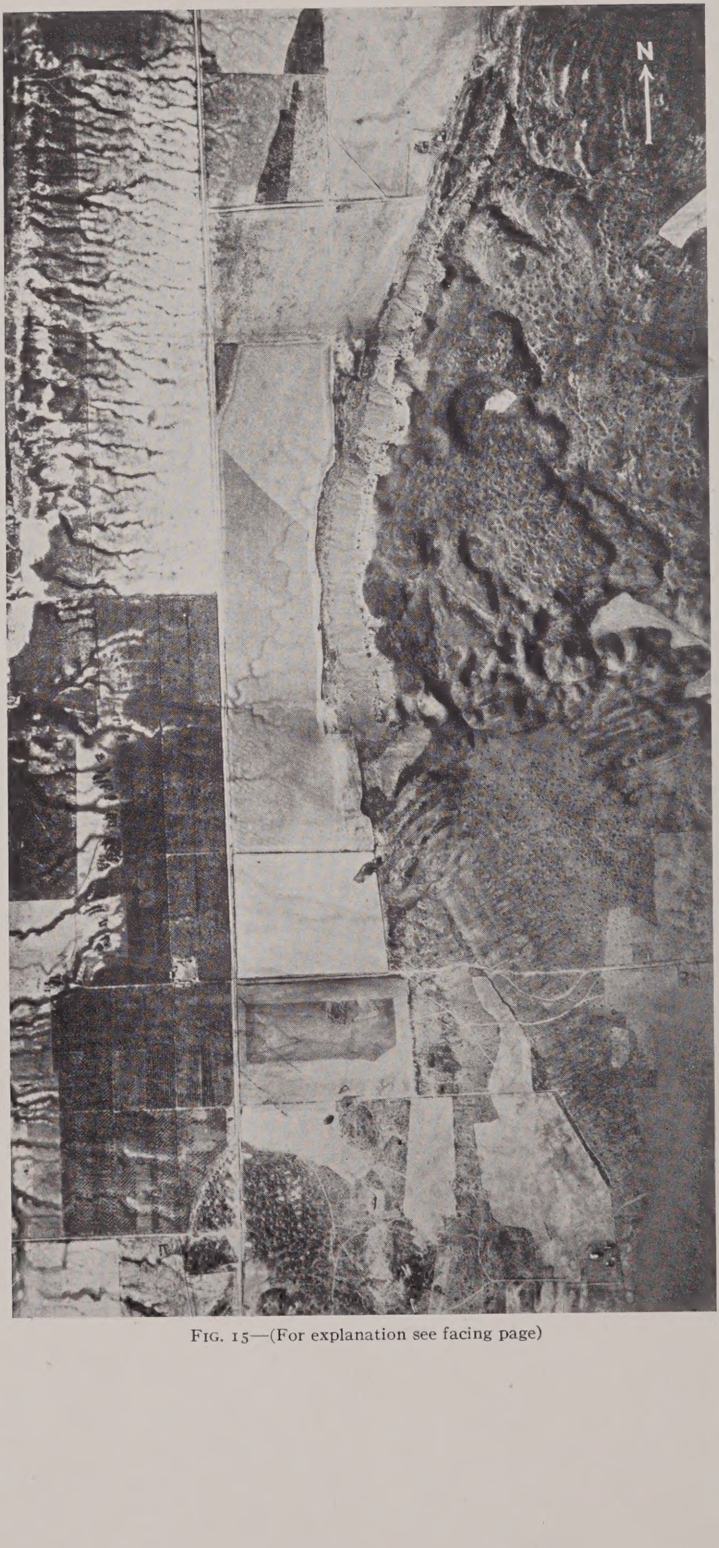

FIG. 15—(For explanation see facing page)

wash plains, or low piedmont waste slopes. More evidence to this effect is to be found along the eastern margin of the gravel. Instead of abutting against older and higher surfaces, the gravel plain here ends abruptly in a steep slope, from thirty to forty feet high, descending eastward and overlooking the lower basin floor. The foreset beds parallel this steep slope.

The Hartline Basin gravel thus becomes an accumulation of flat river bars, all of which were overrun by a broad sheet of water flowing out of Grand Coulee at one time. There are basalt eminences out in the basin, the low northeastern end of High Hill anticline projecting slightly above the gravel. If the surrounding gravel is an ordinary aggradational plain, these low rock hills should still carry their preglacial soil. Instead, they have scabland surfaces. Being nearly isolated in the basin, they afford testimony that the glacial overflow from Grand Coulee, moving on a level surface and in places in an uphill relation to the present slope, possessed marked erosional ability four miles out of and beyond the main channel. Some gravel crossed this scabland and came to rest in its lee, with foreset beds dipping southeastward, away from the tract of bare rock. The evidence from gravel bedding, therefore, is that a current approached this minor scabland from Grand Coulee and that a current departed from the far side of the tract in the same general direction.

Like all scabland gravel, this Hartline Basin deposit is almost perfectly fresh. Its surface is uneroded, and its material is unweathered beneath a zone of slightly reddish

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FIG. 15—Part of the east wall at the mouth of upper Grand Coulee. The silt-covered coulee floor is in the western half of the picture, with a north-south road along it and a spring-irrigated orchard just west of the road. Unirrigated fields margining the road extend to the foot of the talus. The cliff above the talus can be detected by its stronger lighting, though it shows little width. Eroded edges of the tilted flows, striking about N. 45° E., come down to the coulee floor at the south end of the cliff. South of the monocline is the gravel scarp, 100 feet or so in height, in the lee of the scabland salient, whose summit is about 450 feet above the silt terrace. On the salient are two or three crescentic niches, their concavities opening southeastward toward Hartline Basin. The largest of these is identified by a small pentagonal white patch, a desiccated rock basin. The entire summit of the salient is scabland. Northeast of the salient the surface rises in another steep slope, on which at the very edge of the picture is an irregular cultivated field. From this higher slope, above the scabland, normal gullies descend westward toward the coulee and terminate on the brink of the coulee wall. Though they descend below the upper limit of scabland here, they have not been obliterated. Their contrast with scabland forms on the salient is worth noting. (Mosaic of vertical aerial photographs, Grand Coulee Series, 148–151, U. S. Geological Survey.)

staining about two feet deep. The stained gravel shows no softening, and its pebbles of dense basalt have only a very thin rind of alteration, a dulling of the luster and a slight whitening or reddening of the color. Wells in the flat, however, have encountered other sediments beneath the gravel. The widespread loessial soil of the plateau is buried beneath it. An old, decayed gravel has been found close to the base of the scarp between this plain and the coulee floor.[1] The basin already held deposits when the glacial flood arrived. Because of its location out of the main course it became a site of further deposition, and thus the scarp consists of young, fresh gravel above old, decayed gravel. Were this an erosional scarp produced through several successive stages of coulee downcutting, younger gravel should show as terraces on the lower slopes and should not occur on the top.

High Hill Anticline: A Magnified River-Bottom Topography

Distributary escape from this part of Grand Coulee was not limited to the gravel-covered area. The whole adjacent summit of High Hill anticline was overrun. Though much of it is higher than the Hartline gravel plain, it is all scabland of very pronounced character. Figure 16 shows some of this scabland. The basalt yielded by plucking in an almost unbelievable way, and the top and back slope of the fold are scarred in a fashion that must be seen to be appreciated. Scabland channels wind about buttes twenty to fifty feet high in an intricate anastomosis that is wholly unknown in stream patterns. They are not separate streamways; they are subfluvial channels developed beneath one large stream. In this, they have counterparts in some existing Columbia River rapids.[2] No stream bottom has a continuous gradient parallel with the stream surface. Bottom water is constantly flowing upgrade out of deeper holes and over submerged bars.

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[1] Kirk Bryan, personal communication.

[2] See J Harlen Bretz: The Dalles Type of River Channel, *Journ. of Geol.*, Vol. 32, 1924, pp. 139–149.

It erodes these holes, and the débris rolls or leaps upgrade out of them to come to rest in hillocks also under the stream surface. A drained river channel is not a valley in miniature.

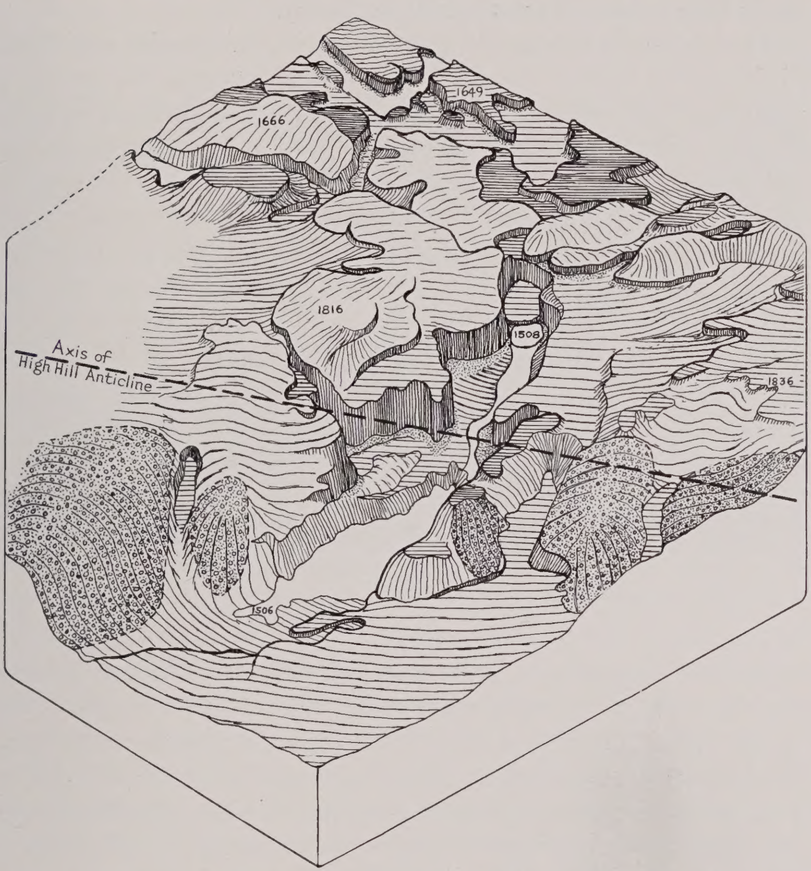

Fig. 16—Block diagram of scabland topography on High Hill anticline. Though the anticline above the upper limit of scabland is a divide, it here has canyons with cataract heads and plunge pools that have receded across the summit almost to Deep Lake. Some of the bars of the southern slope are shown with stippling.

It is a complicated assemblage of hills and hollows. Channeled scabland is river-bottom topography magnified to the proportions of river-valley topography.

If this view is rejected, the summit of High Hill anticline must have suffered intensive erosion from its own run-off, an impossible assumption seeing that all similar folds of the region above the ascribed limit of the glacial flood are deeply soil-covered and totally lacking in rock basins, cliffed buttes, and channels across them. A pattern of local stream courses to fit these channels is utterly fantastic.

The channels run uphill and downhill, they unite and they divide, they deepen and they shallow, they cross the summit, they head on the back slopes and cut through the summit; they could not be more erratically and impossibly designed for separate streamways. We are dealing, on the top of High Hill anticline, with precisely the same topography that marks the coulee channel floor for five miles above the great cataract group. The cataracts prove the coulee floor to be a dry river bed, not a valley bottom nor a group of minor streamways and their divides. So is the top of High Hill anticline.

River Bars in Bacon Synclinal Valley

South of this anticline is Bacon synclinal valley. If our interpretations thus far are in the right direction, the syncline was also under the great stream and must contain its own appropriate river-bottom record. From altitudes of the so-called bar deposits in Quincy Basin we shall not expect that the overflow simply cascaded down the southern slope of the anticline. Water must have been very deep in the syncline. Was this water ponded, or did it have vigorous current? Only very great volume could give it a current adequate for plucking basalt. If water-laid sediments exist, they should record the character of this submergence. They do exist, and they are all river bars. There are no slack-water sediments. Plate I shows that this structural valley near Bacon and thence toward the northeast has a number of large river bars surrounded by scabland. The orientations of these bars are very suggestive. Most of them are elongated toward Spring Coulee, a scabland canyon leading across Pinto Ridge anticline to Crab Creek valley. All are pointed away from High Hill anticline, tailing out in the syncline. The longest bar is a broad mounded ridge of gravel about a mile in maximum width and more than five miles long. It lies along the synclinal axis and, were it not for a break of less than two miles, would be a continuation of the Hartline Basin gravel.

Most of the bars of the syncline are lobate projections out from the southern side of High Hill anticline and into the syncline. Seen from the highway, they are hillside shoulders from fifty to two hundred feet high, hardly suggesting that they are of significance in the problem (Fig. 17). But if one climbs them, one finds that they are mounded gravel piles, reaching well up to the summit scabland on the anticline and projecting southward out into the structural valley beyond the adjacent basalt scabland. The largest bar of this group lies north of Bacon. It is considerably elongated at right angles to the anticline and has a flattish summit about a mile and three quarters long, steep sides on the east and west, and a steep, rounded nose toward the south about two hundred feet high. Its summit has about the same altitude as the scabland on the anticline to the north.

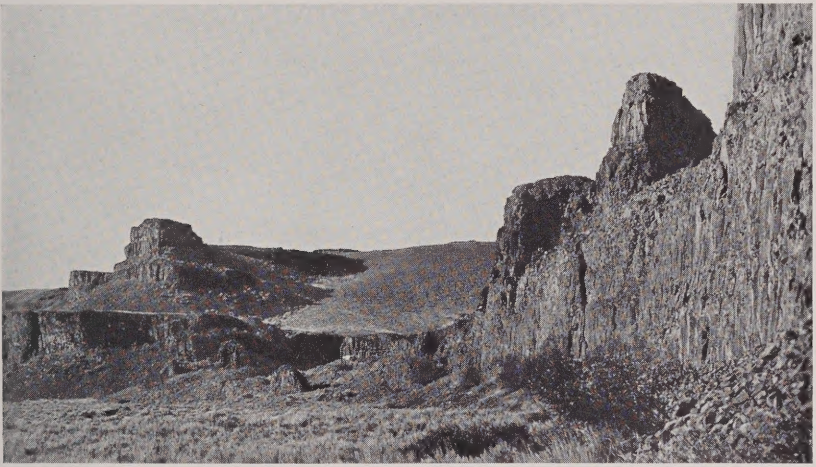

FIG. 17—Scabland buttes and gravel bar at the junction of Lenore Canyon and Dry Coulee. The gravel bar has a vertical range of more than 200 feet, though its thickness may not exceed 50 feet. (Photograph by Simmer.)

On both sides of the distal end of this elongated hill of gravelly débris a deposit of silty material shows between gravel and basalt. The material is about fifty feet thick, and the gravel falls that much short of being as thick as the mound is high. The material is buff in color and apparently unstratified. It is loess and not the varved white glacial silt so prominent in the upper coulee.

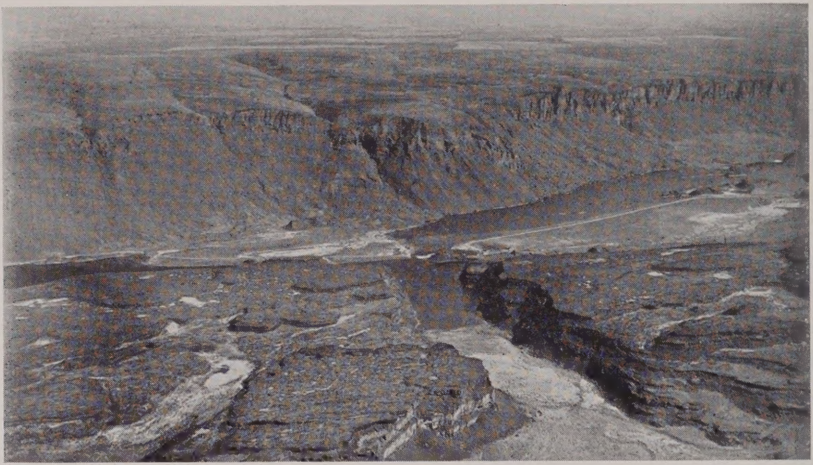

FIG. 18—Jasper Canyon and Park Lake, lower Grand Coulee, looking northwest. The foreground is scabland of the southwestern Hartline Basin, trenched by the distributary canyon. Dipping flows of a part of the monocline show in the middle of the view. The Waterville Plateau, here unglaciated and possessing normal drainage forms, lies back of the western wall. A large bar is traversed by the road in the coulee. Other bars cover the floor of Jasper Canyon. The one nearest the lake is shown in Figure 19. (Oblique aerial photograph by Libby & Son.)

This remarkable bar, with two smaller ones, lies between two canyons eroded in the south slope of the anticline. The heads of both canyons have receded through the crest of the fold. Apparently there were preglacial gullies here, which became greatly enlarged and lengthened while the higher place between was less severely scoured and afforded a lee position in which the bar deposit could form. The nearly level summit of the bar lobe clearly rules out any picture of glacial water tumbling down the southern side of the anticline. Current there was, but the bar grew out into water 250 feet or more in depth.

These bars are not deltas. They lie much higher than the canyons and between them, not at their mouths. They are not terraces left by dissection of a former complete fill of gravel; for they are not bench-like in form, they do not lie along the valley side, they have no systematic relationships of tops, they do not occur on the northern side of the anticline nor on the southern side of the syncline, and they have no gullies on their slopes. They are original constructional forms made beneath a fractional overflow from an almost inconceivably large glacial river. The only missing evidence is structural. No good cuts have been found in significant places.

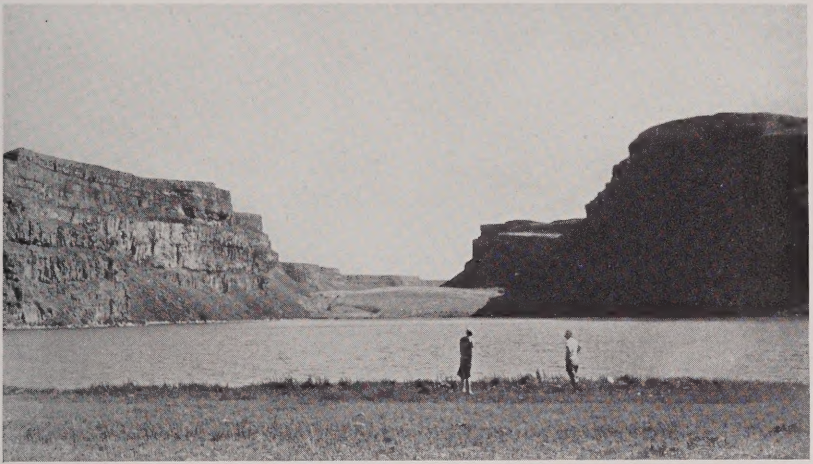

FIG. 19—Jasper Canyon, lower Grand Coulee, looking southeast from the head of Blue Lake. The bar beyond the bay rises 150 feet above the lake, which is 40 feet deep here. A fosse 30 feet deep separates the bar summit from the walls on each side. (Photograph by Beane.)

THE SPECTACULAR LENORE CANYON

Still another overflow from Grand Coulee toward the east is Lenore Canyon, a more spectacular cut across High Hill anticline than is Grand Coulee itself. This is because Lenore Canyon crosses where the topographic summit is high, while Grand Coulee utilizes a sag in crossing the structure. Lenore Canyon seems to be the same type as the canyons on each side of the high bar. Had either of these deepened and lengthened much farther, it would have made a complete transection of High Hill ridge. This Lenore did, becoming a distributary with a floor only 200 to 250 feet above the bottom of Grand Coulee and lacking continuous gradient.

Lenore Canyon is five and a half miles long. It crosses the anticlinal axis about a mile and a half above its junction with Dry Coulee, and thus in the upper four miles of its length its stream flowed against the existing topographic-structural slope. This apparently anomalous relation to regional slopes is readily explicable if the cliff summits along its course be considered. The northwestern slope of High Hill anticline here, 150 to 450 feet above the bottom of Lenore, is all stream-bottom scabland. A greater volume of the glacial flood used this distributary route and succeeded in trenching the ridge to the base. There is no explanation otherwise for this distributary canyon, 450 feet in maximum depth.

Nor was the flood water drawn off the upper scabland as the canyon was cut. It continued to pour into the canyon over the northern wall when Lenore was within less than one hundred feet of its present depth. An abandoned waterfall and plunge pool in this wall and on the upstream side of the anticlinal axis tell this unequivocally. Dry waterfalls are quite common in the scabland of the Grand Coulee region. They apparently developed readily where the glacial water had a steep bottom gradient. The two canyons with the great bar between them have waterfall heads, and very probably Lenore Canyon retreated by undercutting through the ridge.

JASPER CANYON

Jasper Canyon, a still more curious distributary gorge, leads out of Grand Coulee near the head of Blue Lake, a mile and a half north of the head of Lenore. It swings in a curve across the extreme southwestern end of Hartline Basin to come back almost to Grand Coulee, where it enters the head region of Lenore Canyon. In Figure 18 the observer is looking at the upper mile and a quarter of Jasper Canyon, and in Figure 19 he is looking from Blue Lake down Jasper Canyon. The floor is as much clogged with bars as is that of Lenore Canyon and Dry Coulee. The bar shown beyond the lake in Figure 19 rises 150 feet above the water. Cataract recession to make this canyon again seems indicated.

Dry Coulee and Spring Coulee

South of Lenore Canyon the summit of High Hill anticline still possesses its preglacial soil mantle. The ridge was higher here; and the great river surface, being farther downstream, was lower. Bacon syncline crosses from Dry Coulee drainage way to the head of Soap Lake south of High Hill; and, though glacial water filled it, only berg-carried erratics and scattered gravel record the fact. There are no scabland forms here and no bars except along the brink of Dry Coulee.

Into Dry Coulee and Spring Coulee was concentrated all the water that overflowed from Grand Coulee. Spring Coulee cuts across Pinto Ridge anticline at Long Lake. Judging from the orientation of the bars on the south slope of High Hill anticline, Spring Coulee apparently received most of the water. Perhaps Dry Coulee developed as a waterway in the bottom of the syncline somewhat later in the episode. Spring Coulee is a fine scabland canyon, with castle-like buttes, lateral subsidiary canyons, and cataracts notching its walls. The way in which its amphitheater-like head retreated westward around the northern foot of Pinto Ridge anticline suggests that relatively little water was coming from the eastern spillways out of Hartline Basin toward the close of its development. Perhaps Lenore Canyon made its contribution before Dry Coulee had attained its present capacity and depth.

CHAPTER III

GLACIAL ICE IN THE GRAND COULEE REGION

The extraordinary size of some of the isolated gravel hills may well lead readers to question the interpretation of river-bar origin. Why are the gravel hills not as satisfactorily interpreted as kames or gravelly moraine? Why not consider the erratic boulders as glacier-transported instead of berg-carried? Why is not the scabland a product of glacial plucking instead of stream plucking? Fortunately glacial ice has left a characteristic record on a basalt plateau.

Before glacial ice or its water affected the Waterville Plateau, the region bore a submature topography in the large areas above the river canyons.[1] Its character was compounded of two diverse elements; diastrophism and erosion by local streams. The diastrophism had produced a coarse-textured topography, marked by subparallel slopes of the broad anticlines and synclines. On the higher parts of these larger features lay the finer-textured patterns of local stream erosion, the bottoms of the structural valleys alone lacking them.

A loessial soil covered all but the steepest slopes of this compound structural and gradational relief. It still covers most of the region, coming down to the scabland or associated deposits everywhere except along the western side of the upper coulee. Here a till sheet with ridged morainic topography lies back (north) of a terminal moraine, which, a little west of the mapped area, is massive and very sharply defined. In front of the terminal moraine, almost against its foot, is the rolling, submature, loess-covered preglacial topography. Isolated erratics occur here and there but always in situations where they could have been floated in locally ponded water.

The till structure, the foreign débris, and the morainic topography of the superficial material overlie planed, polished, and striated fresh basalt surfaces. The only conventional glacial evidence lacking is outwash gravel beyond the moraine. Instead of valley trains or outwash plains, escaping water on the plateau left channeled scabland. The associated gravel is a product of stream work beyond the ice edge, rather than a rehandling of débris from the ice itself.

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[1] Possibly this topography in part is older than the uplift that warped the original plane surface of the basaltic plain and initiated the present major river canyons.

A lobe of the Cordilleran ice sheet crossed the Columbia Valley west of Grand Coulee and pushed about thirty miles southward up on the Waterville Plateau.[2] This made the Grand Coulee detour of the glacial Columbia. How many times this occurred is unknown. The terminal moraine has generally been considered as Wisconsin in age. There may have been several earlier blockades; but, if so, the latest was the most extensive. From this it follows that we do not yet know how many Pleistocene glacial epochs were involved in the making of Grand Coulee. Certainly there were two, probably there were more. During the recorded glaciation the eastern edge of the Okanogan lobe on the Waterville Plateau pushed partially or completely across the northern part of the upper coulee after the coulee had been eroded to present depths. The evidence is as follows.

The Case of Steamboat Rock

The summit of Steamboat Rock (Fig. 20) has good scabland topography with a relief of more than a hundred feet. A channeled trench at least a hundred feet deep is cut from side to side completely across the southern part, and remnants of a still larger and deeper channel make the scabland bench about halfway up the eastern cliff. Superposed on the summit scabland is a moraine ridge about thirty feet high, and thousands of erratic boulders lie scattered all over the top. Glacial striae, oriented about S. 20° E., have been found on the extreme southern part of the summit. Though ice did not greatly modify the scabland, it clearly arrived after the channeling was completed.

Granite knobs on the floor of the coulee, north of this

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[2] Though earlier noted, its course was first described by R. D. Salisbury, *Journ. of Geol.*, Vol. 9, 1901, pp. 718–731; reference on p. 721.

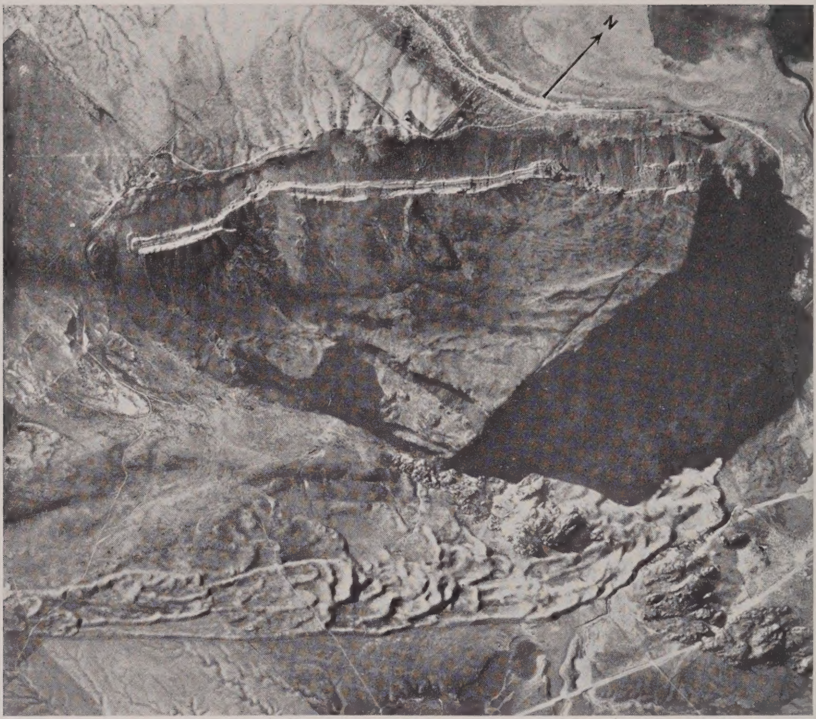

FIG. 20—Steamboat Rock, upper Grand Coulee. Only the northwestern cliff is well illuminated. The eastern cliff is entirely unlighted, and its shadow in one place crosses Northrup Creek, being nearly as long as the cliff is high. The only route to the top is up the southeast side. (Vertical aerial photographs, Grand Coulee Series, Nos. 221–223 and 237–241, U. S. Geological Survey.)

basalt butte, are smoothed and rounded on the northwest, as if by glacial overriding. Though no good striated surfaces have been found on the crumbling granite, there are groovings on the rounded surfaces that parallel the striae on Steamboat Rock.

No till or morainic topography has been identified in association with the granite knobs. The unconsolidated material of the coulee floor is almost wholly a very light-colored water-laid silt, now dissected into a multitude of small ravines and furrows. This silt appears to have been deposited over some irregularly contoured, bouldery, and gravelly accumulations, the nature of which is now largely concealed. A buried ridge of such material depends southward from Steamboat Rock for about four miles, approaching within

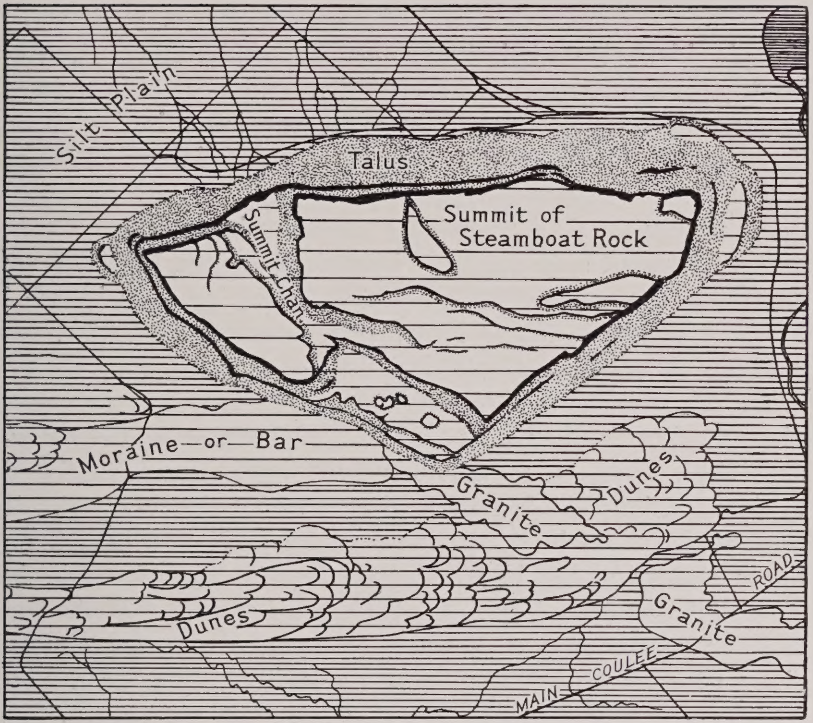
Silt Plain
Talus
Summit of Steamboat Rock
Summit Chan.
Moraine—or—Bar
Granite
Dunes
Dunes
Granite
ROAD
MAIN COULEE

FIG. 21—Line drawing from Figure 20. The southern end of Devils Lake is in the upper right-hand corner. A long row of marching dunes lies on the coulee floor east of the Rock. Here also are low granite knobs, crossed by the main road along the coulee.

half a mile of the eastern wall. There it turns westward in a smooth curve, crossing the coulee and returning for about a mile along the base of the western wall. This may be a moraine loop, now silt-covered, made when ice reached the top of Steamboat Rock.

LIMITS OF THE GLACIAL ICE

It seems clear that glacial ice invaded this part of Grand Coulee after its excavation. Did it completely block the coulee? The scabland above the top of the western wall certainly was overridden, its characteristic vertical elements obliterated or considerably reduced, and its basins partly filled. It is still scabland, especially marked when seen from a height of two miles. There also are striated and polished basalt surfaces near the head of Barker Canyon, a tributary on this side, oriented similarly to those on the top of Steamboat. And, like Steamboat, this scabland has thousands of scattered erratic boulders. In contrast with this the upper scabland east of the coulee apparently carries no till, has few erratics (and those presumably berg-borne), possesses more nearly vertical walls of buttes, basins, and channels, and no striated surfaces have been found upon it. Nor are there any known suggestions that glacial ice ever invaded the loess-covered plateau immediately east of the coulee.

Since the scabland and its closely associated mounded gravel deposits extend a hundred miles farther south and ninety miles farther east and have stream-channel characteristics everywhere and nowhere have any associated typical glacial records except along the northern margin, it seems safe to conclude that the limits of glaciation have been fairly closely approximated. The large areas of maturely dissected loessial soil without a trace of glacial records and the narrowness of most of the scabland tracts make it especially difficult to conceive that glacial ice, either as a continuous sheet or as tongues along the scabland routes, has been in the region since the loess was deposited.

CHAPTER IV

THE HISTORY OF GRAND COULEE

Earlier Interpretations

The first published suggestion for the origin of Grand Coulee is to be credited to the Rev. Samuel Parker.[1] While investigating the opportunity for establishing Indian missions in the northwest he crossed the coulee presumably between the two canyoned portions in 1835. He writes that the coulee "was indubitably the former channel of the river (Columbia)."

For forty-five years after this comment was made, there seems to have been no printed mention of the problem of Grand Coulee. Then Lieutenant T. W. Symons of the United States Army traversed the upper canyon, to which the name of Grand Coulee was then restricted, and saw something of the environs. He thought[2] that Grand Coulee and "the courses of many of the most deeply encanyoned rivers of this country were determined to a very great extent by their waters finding and collecting in great fissures." He suggested that "during . . . the Champlain epoch this canyon (Columbia Valley north of the plateau) was filled up by debris, bowlders, etc. to a height of 2000 feet above the present river surface. . . . During this epoch also the Grand Coulee was occupied as a secondary channel by the Columbia. . . ." Though he recognized the glacial origin of the Lake Chelan trough and the fact that the region about Spokane had been glaciated, he did not utilize glacial ice either as a dam or as a source for the water.

Professor I. C. Russell, eleven years later, discussed the origin of Grand Coulee[3] and introduced the idea that erosion along a line or zone of fracture and faulting had determined its location. The lower canyon, by this time also included under the name Grand Coulee, was clearly determined by a belt of sharp deformation, and Russell apparently thought that the location of Grand Coulee had been determined by a line of fracture and faulting. Seemingly he thought the upper coulee marked the northeastward continuation of the line of deformation. Curiously, he reversed the direction of dip in the monocline along the lower coulee, stating that it is "west, away from the canyon, at an angle of 8° to 10°." He thought that a north-draining preglacial drainage line existed along the upper coulee and that its waters cascaded to the Columbia from the coulee head. The advent of glacial ice reversed the direction of flow and gave rise to a huge cataract south of Coulee City (the present Great Cataract group). Though his explanation requires a preglacial divide, he did not specifically locate one.

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[1] Journal of an Exploring Tour Beyond the Rocky Mountains, Auburn, N. Y., 1838.

[2] T. W. Symons: Report of an Examination of the Upper Columbia River, *47th Congr., 1st Sess., Senate Doc. No. 186*, 1882.

[3] I. C. Russell: A Geological Reconnaissance in Central Washington, *U. S. Geol. Survey Bull. 108*, 1893.

Within five years Grand Coulee's origin was again mentioned in print, W. L. Dawson[4] adopting Russell's ideas and adding an item. He considered that the course of the entire coulee was determined by "a fracture line in the lava." He placed a preglacial divide near Coulee City, draining the precursor of upper Grand Coulee northward to the Columbia. "The waters of the (glacial) Columbia deepened this channel and planed down the divide." He noted the great cataract group, "in comparison with which Niagara is a mere bagatelle."

A departure from Russell's ideas came seven years later. F. C. Calkins[5] declined to accept the idea of faulting along lower Grand Coulee, pointing out that the structure was a monoclinal fold. He also correctly described the monocline as constituting the northern slope of Hartline Basin and not continuing along the upper coulee. Calkins explained the coincidence of the lower coulee and the flexure by accepting Russell's suggestion (for another region) that the location of folds has been determined by weakening of the rock through earlier erosion along stream courses. Thus there had to be a Grand Coulee drainage way before the folding occurred. But he also referred to Grand Coulee as carved by Columbia River at a time when its gorge was dammed by a great ice lobe. Apparently the upper coulee is here referred to. He said nothing specific about the location of a preglacial divide near Coulee City.

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[4] W. L. Dawson: Glacial Phenomena in Okanogan County, Washington, *Amer. Geologist*, Vol. 22, 1898, pp. 203–217.

[5] F. C. Calkins: Geology and Water Resources of a Portion of East-Central Washington, *U. S. Geol. Survey Water-Supply Paper No. 118*, 1905.

In 1912 occurred the American Geographical Society's Transcontinental Excursion. Professor Karl Oestreich, of the University of Utrecht, was a member of the party and in the volume which memorialized the excursion[6] described the coulee in more detail than any earlier writer. To him it appeared as "eines mächtigen Flusses Bett . . . ohne jede Spur von Zerfall der frischen Form." Steamboat Rock, the exhumed granite hills, the perpendicular walls, and the great width of flat bottom were noted and particularly the hanging valleys of the upper coulee. These he considered as preglacial tributary valleys. Two explanations for the hanging condition were proposed: (1) deepening of the coulee by the glacial Columbia, and (2) glacial erosion by a tongue of ice occupying the upper coulee for a time. He suggested that the preglacial divide was located near Coulee City, the predecessor of the upper coulee thus draining northward to the Columbia.

Six years after the excursion, Grand Coulee was again discussed in print. Dr. O. E. Meinzer in a brief paper[7] held that the glacially-diverted Columbia at Grand Coulee "cut precipitous gorges several hundred feet deep, developed three cataracts, at least one of which was larger than Niagara, . . . and performed an almost incredible amount of work in carrying boulders many miles and gouging out holes as much as two hundred feet deep." He appears to have thought that the glacial river descended the monoclinal slope at Soap Lake, the great cataract group taking origin here and retreating seventeen miles to the present position. The lower coulee thus interpreted is a Niagara gorge in origin. Dry Falls "were somewhat wider and higher than Niagara Falls." Grand Coulee was to him "an abandoned channel." No preglacial valley on the site of the coulee is implied, the glacial ice "diverting the waters of the Columbia over the upland."

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[6] Karl Oestreich: Die Grande Coulée, in "Memorial Volume of the Transcontinental Excursion of 1912" [*Amer. Geogr. Soc. Special Publ. No. 1*], 1912, pp. 259–273.

[7] O. E. Meinzer: The Glacial History of Columbia River in the Big Bend Region, *Journ. Washington Acad. of Sci.*, Vol. 8, 1918, pp. 411–412.

A still briefer mention of the problem of Grand Coulee appeared four years later. J. T. Pardee remarked in a note in *Science*[8] on "an ice stream which, as shown by recent observations, traversed the (Grand) coulee itself." He said nothing about the character of the evidence for this statement or about modifications of coulee form attributed to this glaciation. How much of the coulee was traversed by ice is not indicated.

Grand Coulee was discussed again within a year, the present writer[9] stating that "no preglacial drainage route ever existed" along the course of Grand Coulee, that glacial drainage made the entire canyon, and that "it is very probable that this immense task was performed by the stoping of cascades and cataracts which retreated entirely through the monoclinal uplift to the deeper valley of Columbia River and thus left the great notch." A footnote reads, "This inference has no known physiographic evidence in Grand Coulee to substantiate it but is based on the known procedure of glacial streams in similar situations, e. g. Lower Palouse Canyon, Devils Canyon, Frenchman Springs, and The Potholes." The present work contains the now-known physiographic evidence.

The next reference to the coulee which involved new ideas was made four years later, both Dr. O. P. Hay and Professor Kirk Bryan contributing.[10] Hay, who wrote the report, referred on page 257 to an unpublished report by Kirk Bryan containing the following ideas regarding Grand Coulee. (1) Hanging valleys record an ordinary preglacial stream on the site of the upper coulee. (2) The surface of the Hartline gravel fill records an early stage in making the coulee. (3) A terrace near the base of the gravel scarp between Coulee City and Hartline Basin records a later stage of glacial stream erosion. Bryan's idea clearly is that the upper coulee was sawed down from the top, not plucked out from the end. Hay, commenting on *Camelops* or *Camelus* bones found in the lower "terrace," thought that the history of Grand Coulee must run through the whole of the Pleistocene and that the loess is younger than the Hartline gravel fill.

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[8] J. T. Pardee: Glaciation in the Cordilleran Region, *Science*, Vol. 56 (N. S.), 1922, pp. 686–687.

[9] J Harlen Bretz: The Channeled Scablands of the Columbia Plateau, *Journ. of Geol.*, Vol. 31, 1923, pp. 617–649.

[10] O. P. Hay: The Pleistocene of the Western Region of North America and Its Vertebrated Animals, *Carnegie Instn. Publ. No. 322 B*, 1927.

In a popular account of the Grand Coulee compiled by J. G. McMacken,[11] in which diverse earlier interpretations are incongruously mingled, the amount of excavation in eroding the coulee is greatly overestimated, several new statements are made which conflict with the field evidence, and one mistake is made in the three lone credit items for previous work. The ideas of Steamboat Rock as a Goat Island and Northrup Canyon as a cataract recess appear here for the first time in print.

Following this review we proceed to the writer's interpretation of the history of Grand Coulee.

PREGLACIAL TOPOGRAPHY

Before the earliest glacial damming of the Columbia there was no drainage way across the divide on the site of Grand Coulee. There did exist a southward-draining valley way between the Coulee monocline and High Hill anticline. Adjusted to this, tributary gullies had developed on the east-facing monoclinal slope and on the western slope of High Hill, remnants of which are still conspicuous features. Hartline Basin, the broadened northeastern extension of this structural valley way, had similar gullies all around its margin, more than half of which were not reached by the glacial water and which therefore exist today. The mouth of the upper

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[11] J. G. McMacken: Grand Coulee of Washington, *Pan-American Geologist*, Vol. 55, 1931, pp. 81–92.

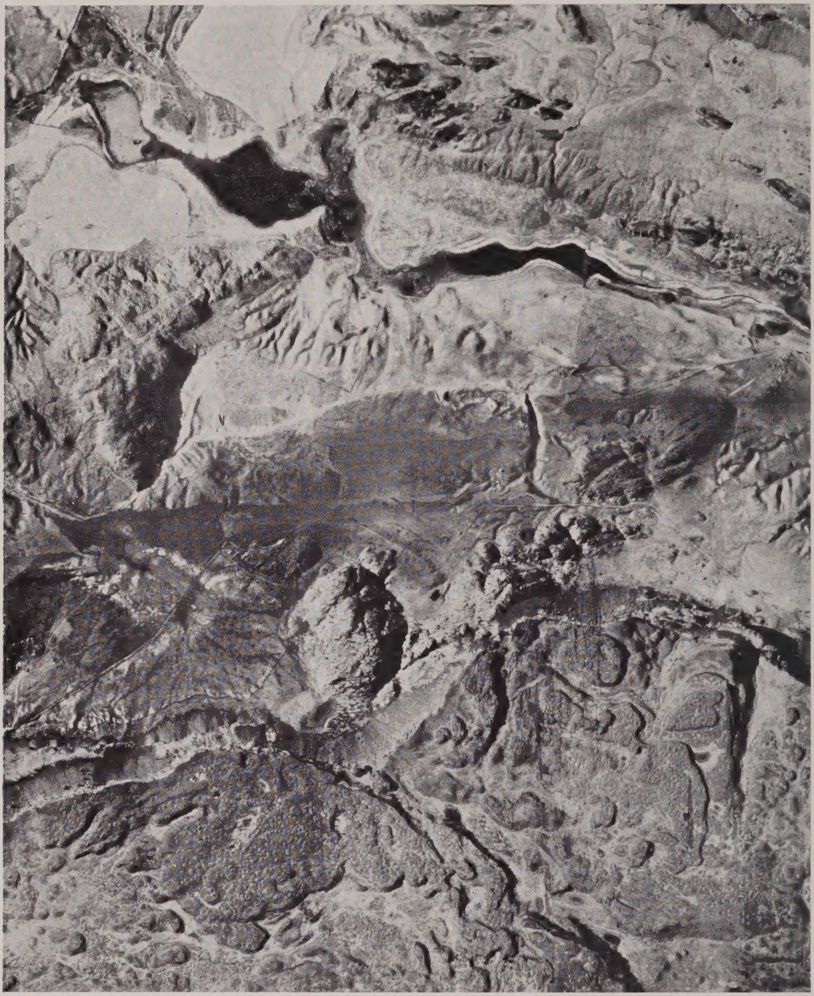
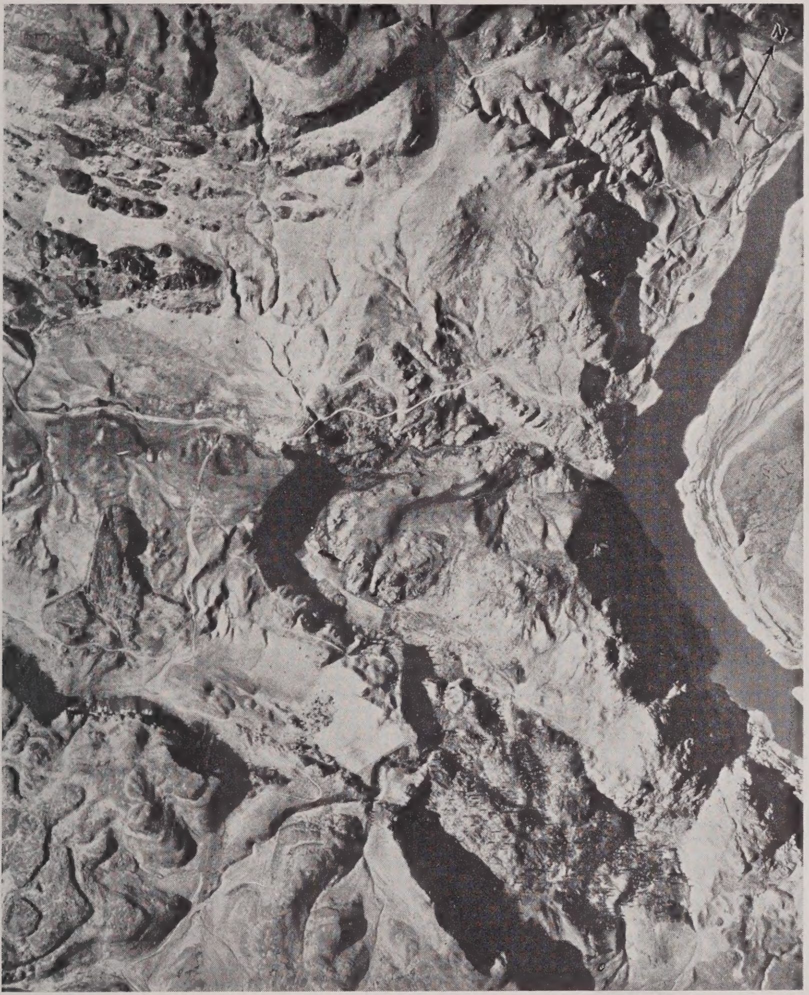


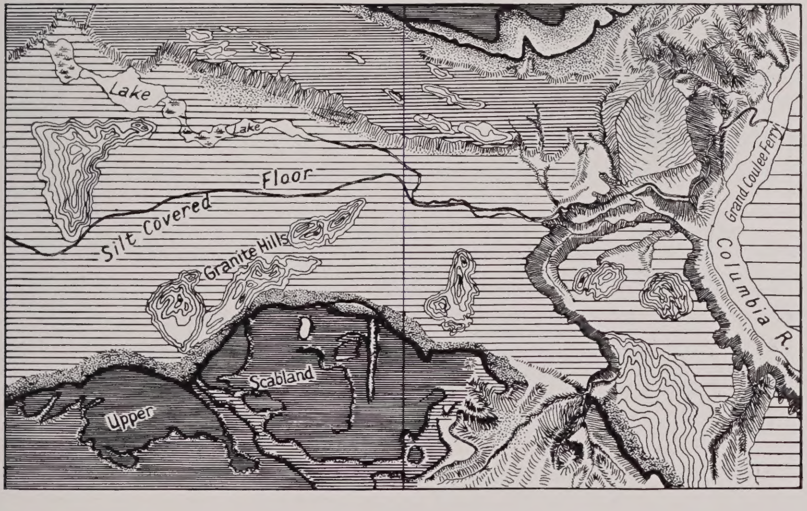
FIG. 22 (pp. 44 and 45)—Columbia River Valley and head of Grand Coulee. Cliff shadows fall to the right. The summit scabland of the eastern side of Grand Coulee shows in the lower part of the view. The Columbia River, at the bottom of the deep valley on the extreme right of the right hand half of the view, is 1500 feet below the summit scabland, and the dissected silt floor of the coulee, carrying swamps and lakes and interrupted by granite hills, is about 1000 feet below.

The Columbia Valley slope is marked by normal ravines and gulches, all of which are eroded in granite. Basalt does not lie lower than the base of the coulee walls. The walls (which can be traced by their talus slopes) lack such normal valleys except at the very head of the coulee where they are close to the Columbia. Here are several large ravine heads, some of them hanging above the coulee floor, and so oriented that they are best interpreted as remnants of pre-scabland ravines, tributary to the Columbia. One of these, which shows well its origin by normal run-off, is utilized by the road southward from the coulee floor to the summit scabland in the lower part of the view. An undissected silt terrace, extending from the river valley into the coulee, is crossed by this road.

A dome-like granite hill on the coulee floor lies partially in a reëntrant of the eastern wall in the left half of the picture. To the lee (left) side of this may be seen a mounded gravel bar with the talus encroaching on it and its fosse. The bar summit stands 150 feet above the floor and 50 feet above the bottom of its fosse. This bar is illustrated and described in the writer's paper "Bars of Channeled Scabland" (*Bull. Geol. Soc. Amer.*, Vol. 39, 1928. See Pl. 20, Figs. 2 and 3 and p. 670). (Mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 91–107 and 206–210, U. S. Geological Survey.)

FIG. 23 (p. 45)—Line drawing from Figure 22 to half scale.


N


Lake
Lake
Floor
Silt Covered
Granite Hills
Scabland
Upper
Grand Coulee Ferry
Columbia R.

coulee probably was marked by a larger gully than any of those surviving, but its tributary heads, now hanging high above the upper coulee floor, do not indicate any notable canyon here. The northern end of the upper coulee similarly had a good-sized gulch leading down to the Columbia but no real canyon. The floor at the head of the coulee is 500 to 600 feet above the river, yet less than a mile distant. Tributaries of this gulch are recognizable in Figure 22.

The highest part of High Hill anticline (2000 feet above sea level) remains in its preglacial condition, with smooth slopes and a complete cover of loessial soil. Farther northeast the topographic summit of the fold was about 200 feet lower but as much as 300 feet above the adjacent Bacon syncline and 50 to 100 feet at the most above Hartline Basin.

Bacon syncline probably had a divide in it near Bacon station. Dry Coulee drainage way then headed in the sag between High Hill and Pinto Ridge. At Bacon, the syncline drained eastward into Spring Coulee, itself an antecedent streamway across Pinto Ridge anticline. Lenore Canyon was then but a short gully at the extreme eastern end of the present canyon.

Hartline Basin had two dischargeways at this time. One was southward toward the location of Soap Lake along the basin's synclinal extension. This was the predecessor of the lower coulee. The other was a fairly broad erosional valley southward in the eastern end of the basin, around or across the lowered extremity of High Hill anticline. This drainage line was the headwaters of Spring Coulee, traversing a part of Bacon syncline to enter the antecedent course.

The above reconstruction is based on the following facts and inferences:

1. Except in channeled and glaciated tracts, the Columbia Plateau in Washington carries an essentially continuous, smoothly contoured loessial mantle. Ledges of rock are rare.

2. The topographic slopes in the region conform to the structural slopes. Streams are largely consequent.

3. The erosional topography of loess-covered portions is older than that of the channeled portions. The scabland

(and its gravel) has relatively little dust, little gullying, little weathering, is uniformly lower than the adjacent loess-covered areas, and is much younger in terms of its striking cliffed forms and its unfilled basins.

4. The channeled scabland is a product of glacial stream erosion. The character of the drainage derangements, the indicated directions from which the water came, the deposits, and the erratic boulders widely distributed along these channelways establish this conclusion.

5. The depth of glacial stream erosion can be approximated from depths of the scabland channels, canyons, and basins; from the heights of the bare rock buttes, walls, and dry cataracts; and from the relations of hanging tributaries of the earlier normal drainage to the channels and canyons.

6. The widths and depths of the glacial streams can be approximated by the width and relief of uncanyoned scabland tracts; by the widths of abandoned cataracts; and by the depths of rock basins and the heights of river bars.

Development of the Upper Coulee

Let us first consider the developmental stages of the relatively simple upper coulee. With the first discharge of glacial water across the plateau, the lowest available place on the divide brought the stream down the monoclinal slope into the western end of Hartline Basin. It descended from the southernmost upper scabland to a basin floor that was lower than the gravel plain east of Coulee City. The fall was about 500 feet in two miles. There was no valley on this slope large enough to serve as a channel; and the water spread, even on this steep gradient. A part of the initial cascade appears to be still preserved in the indubitable glacial-stream scabland of the salient four miles north of the town (see Fig. 15). If we set up such an hypothesis and then deduce its consequences, two alternatives appear. Either the gigantic cascade will lower its gradient because greater erosion occurs at the top of the incline, or it will steepen its gradient because of greater erosion at the base of the descent. In the first case the great cascade becomes a rapid which finally wears itself out as the head is extended farther upstream and the canyon is lengthened. In the second case the cascade becomes a cataract, and by its recession the canyon is formed. These are fundamentally different procedures. Which occurred?

It is hardly necessary to inquire into the fitness of Columbia basalt sheets for developing and maintaining recessional cataracts. Only five miles distant is a compound cataract magnificently displayed. In it are falls, wide and narrow, regular and irregular, high and low, and there probably were great variations in stream depths on the brinks of all of them. A receding waterfall mechanism would operate readily in horizontal sheets of Columbia basalt.

But one hesitates to complete the picture. At the mouth of the upper coulee, the width is a mile and a half, and from scabland on top of the walls to scabland on the floor the drop is 600 feet or more. Could any conceivable stream ever maintain such a waterfall? If we accept this picture, we can never explain Grand Coulee as already partially excavated by a pre-Pleistocene Columbia and the glacial stream as returning to the early course which a gigantic piracy, perhaps, had left marooned on the dry plateau top. We cannot explain Grand Coulee as a river valley—the cumulative product of stream corrosion and slope weathering. We cannot find a record of successive stages of downcutting in the walls of the canyon. We must begin with a cataract, without "Goat Islands," a mile and a half wide, itself concentrated from a wider stream above the brink. Upper Grand Coulee becomes, in this view, a Niagara Gorge, except that it is three times as deep and at the maximum nine times as wide.

Let us examine the upper coulee again. Why does a rock floor exist above the great cataract group as far as, but no farther than, the place where the hypothetical cataract developed? Why is there no rock on the floor as far upstream as Steamboat Rock? Why does this upper coulee floor contain a basin for eighteen miles of its length? Why is rock bottom more than two hundred feet beneath the water-laid materials that constitute the basin floor?

Other questions arise concerning the curious amphitheater-headed tributary niches and lateral canyons that occur only where channeled scabland stream bottom lies on top of the great walls. The huge mid-coulee butte, Steamboat Rock, is a peculiar feature for the middle of a stream valley. The numerous granite hills that obstruct the coulee farther north: how did the stream excavate to almost equal depths around them all? And why do the Northrup tributary canyon heads return almost to the coulee walls?

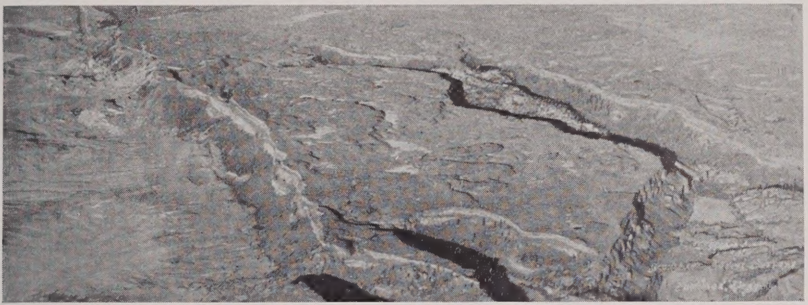


FIG. 24—Heads of Northrup Canyon group, upper Grand Coulee, looking northeast. The dissected silt deposit on the floor of the coulee shows on the left. The summit scabland is about 900 feet higher. A median granite ridge shows in the most distant canyon. Note the canyon head that notches the coulee wall, lower edge of the photograph. (Photograph by Brubaker.)

If we start a receding cataract at work, we shall explain the rock basin in the coulee bottom as a greatly elongated plunge pool, the amphitheater-headed niches and lateral canyons will become intelligible as "American Falls" abandoned as the greater cataract outran them, the Northrup canyons will record unusual lateral cataracts that almost returned to the main, Steamboat Rock will become a Goat Island behind which the twin falls flanking it joined again, and the upper scabland must remain stream bottom until the retreating cataract reaches it. Once we start the cataract at the monoclinal cascade, no shift to any other mechanism is permissible. The coulee must be completed logically on the premise with which we begin.

Having dared to make the above interpretations, let us take another look at the coulee. For eleven miles above the monocline it maintains a fairly constant width, ranging from

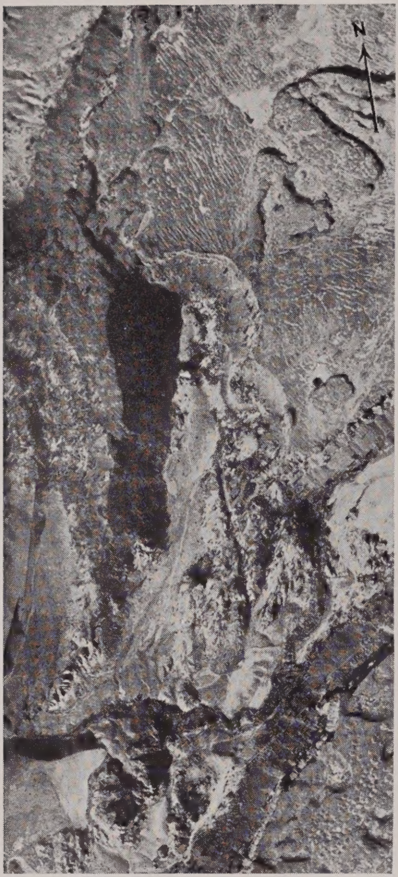


FIG. 25

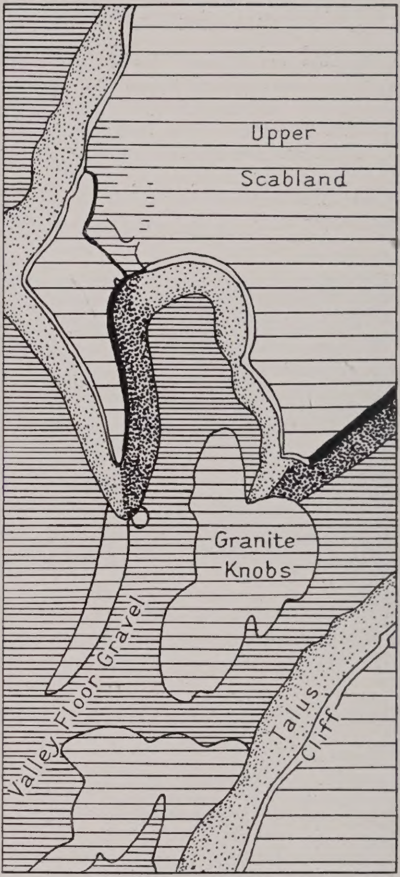


FIG. 26

FIGS. 25 and 26—Middle alcove of Northrup Canyon group, upper Grand Coulee. The cliffs facing north and east are in shadow. Grand Coulee floor and cliff show in the northwest corner. Summit scabland occupies most of the northern half of the picture and a little of the southeastern corner. The main Northrup Canyon crosses from the southwest corner to the middle of the east side. The alcove is in the center. Note channels leading to it from the brink of the coulee wall. Granite hills constitute the angle between the alcove and the main Northrup Canyon. (Fig. 25 mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 112–116, U. S. Geological Survey.)

a mile and a quarter to a mile and a half. North of this, however, it becomes wider and in a short two miles it doubles in width. In another two miles upcoulee, the doubled width is itself almost doubled, the total there averaging nearly five miles. For ten miles the coulee is extraordinarily wide for any streamway with nearly vertical walls. These walls also are unusually irregular in ground plan, whereas south of the widened place the coulee cliffs are fairly straight and nearly parallel with each other. Here in the midst of this widened coulee floor is the big basalt butte we just suggested as a Goat Island. Here stand most of the granite hills, some of them nearly as high as the coulee cliffs. Figure 2 is an average landscape in this part of the coulee. If committed to the idea of coulee origin by waterfall retreat, the five-mile width just examined demands a cataract equally wide. Unless we are totally lacking in a sense of caution, we may well hesitate again. Cannot the island-like rock hills be used to fill up the channel and thus push the walls farther apart? We earlier noted that in one place a row of those hills, measured two hundred feet above the coulee floor, occupies two-fifths of the coulee width. But, alas for our suggestion, this row marks one of the narrowest places in the widened portion.

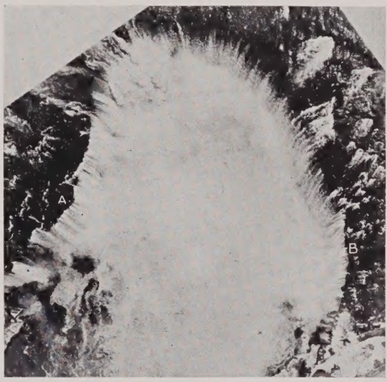


FIG. 27—Horseshoe or Canadian Fall, Niagara. The width from A to B is one-eighth of a mile: the width of the middle alcove of the Northrup Canyon group (Figs. 25 and 28) is one-third of a mile. (Photograph by courtesy of Royal Canadian Air Force.)

The eastern wall of the wide upper coulee has the Northrup Canyon group, itself equal to a Niagara Gorge in width and to three such gorges in depth (see Pl. I and Figs. 24, 25, and 26). The western wall shows a somewhat similar lateral canyon (Barker Canyon), leading back into the upper scabland (unfortunately not completely mapped), and half a dozen amphitheater niches. If these are abandoned "American Falls," as suggested, we are being drawn despite all hesitation into acceptance of the cataract hypothesis.

The greatest of these niches, at Hubbard Creek, is recessed a mile and a half back into the upper scabland and is almost two miles wide at its mouth. The wall is a vertical cliff, like

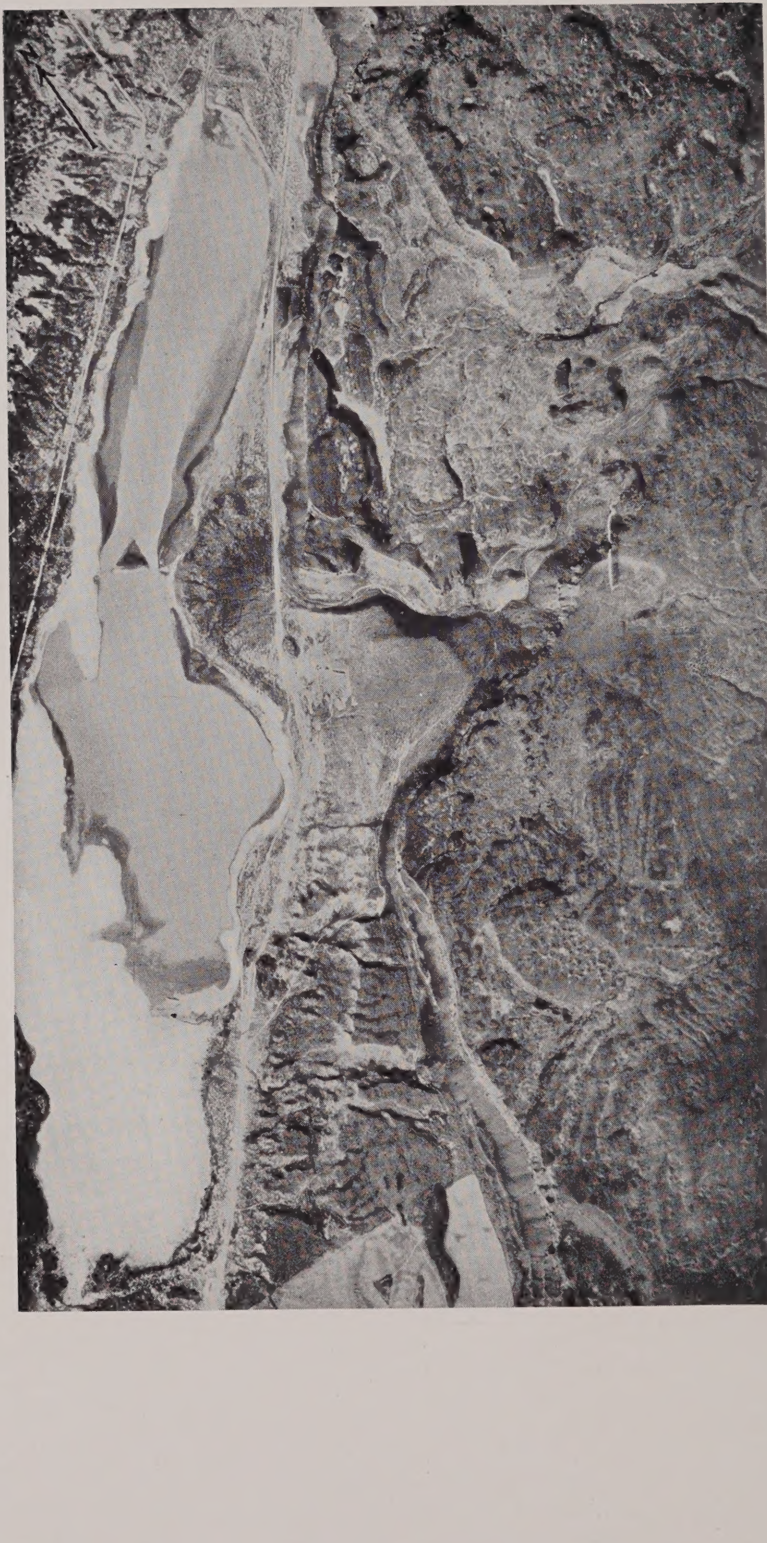


FIG. 28—Lateral cataract recess and bar, upper Grand Coulee. The ephemeral lake on the coulee floor is nine miles north of Coulee City. A delta fan has been built into it by a gully from the east, the gully eroded in a large bar in the lowest part of the niche. Elsewhere the floor is the silt plain. (Mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 139–143, U. S. Geological Survey.)

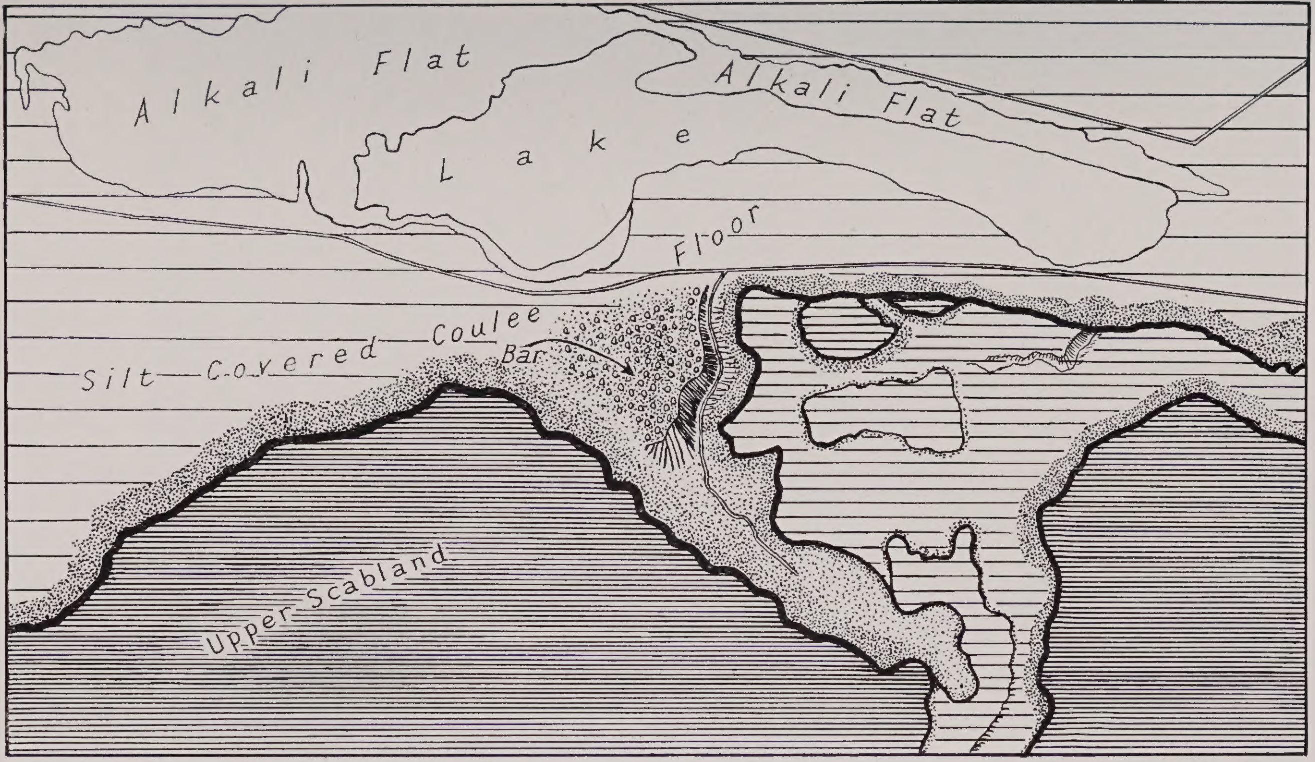

Alkali Flat
Alkali Flat
Lake
Floor
Silt Covered Coulee
Bar
Upper Scabland

FIG. 29—Line drawing from Figure 28. The niche in the east wall is rudely triangular in plan, and most of it is only about half as deep as the coulee. The bar, where the niche is full depth, is 165 feet above the lake flat and 85 feet above the fosse between it and the coulee wall. Another view of the bar is shown in Figure 51. The gully slope can be readily distinguished from the original bar slope in both.

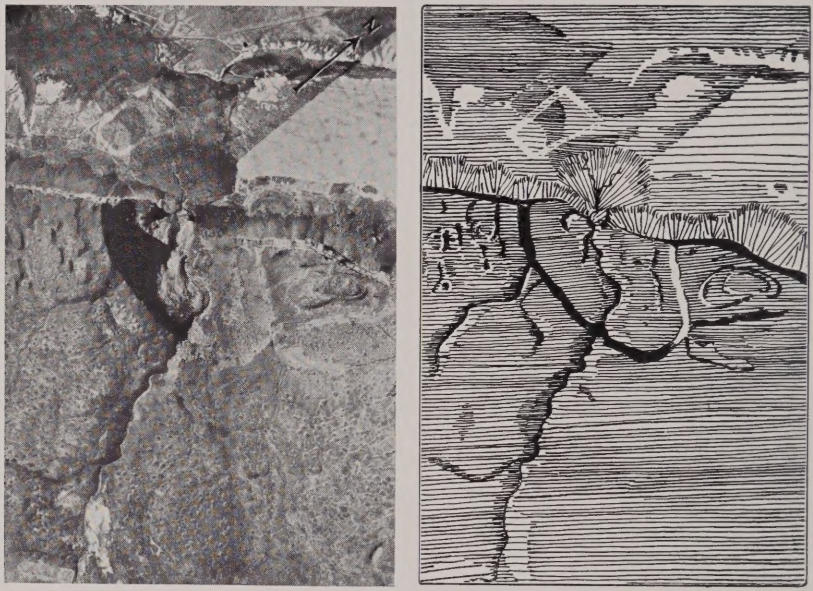


Fig. 30 Fig. 31

Figs. 30 and 31—Lateral cataract recess, upper Grand Coulee. The silt-covered coulee floor occupies the upper third of the view; and the coulee wall, crossing from side to side, separates this from the summit scabland to which the alcove belongs. The amphitheater is a third of a mile long and about as wide at the mouth. It hangs about halfway on the coulee wall, as shown in Figure 4. Its southern cliff is in deep shadow, and its northern cliff is so evenly lighted that more than casual inspection will be needed to locate it. (Fig. 30 mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 127–129, U. S. Geological Survey.)

the main coulee walls elsewhere. Can it be an old meander scar? If so, the working hypothesis is all wrong. But the rock knobs and hills on the coulee floor, much more numerous than the fifty-foot contours show (Pl. I), debar this idea. Can it be a pre-silt, post-coulee breaking down of an original straight wall here, a spring alcove like those of the Snake River lava plains? If so, where has the débris gone? There are rock basins, unfilled even with the silt, between it and the Columbia. There are no springs at its head and no larger spillover here of storm water than over walls that show no niching. Though differently proportioned, it is genetically the same as the other niches and as the Northrup group. It fits into the hypothesis perfectly and seems to have no other satisfactory explanation.

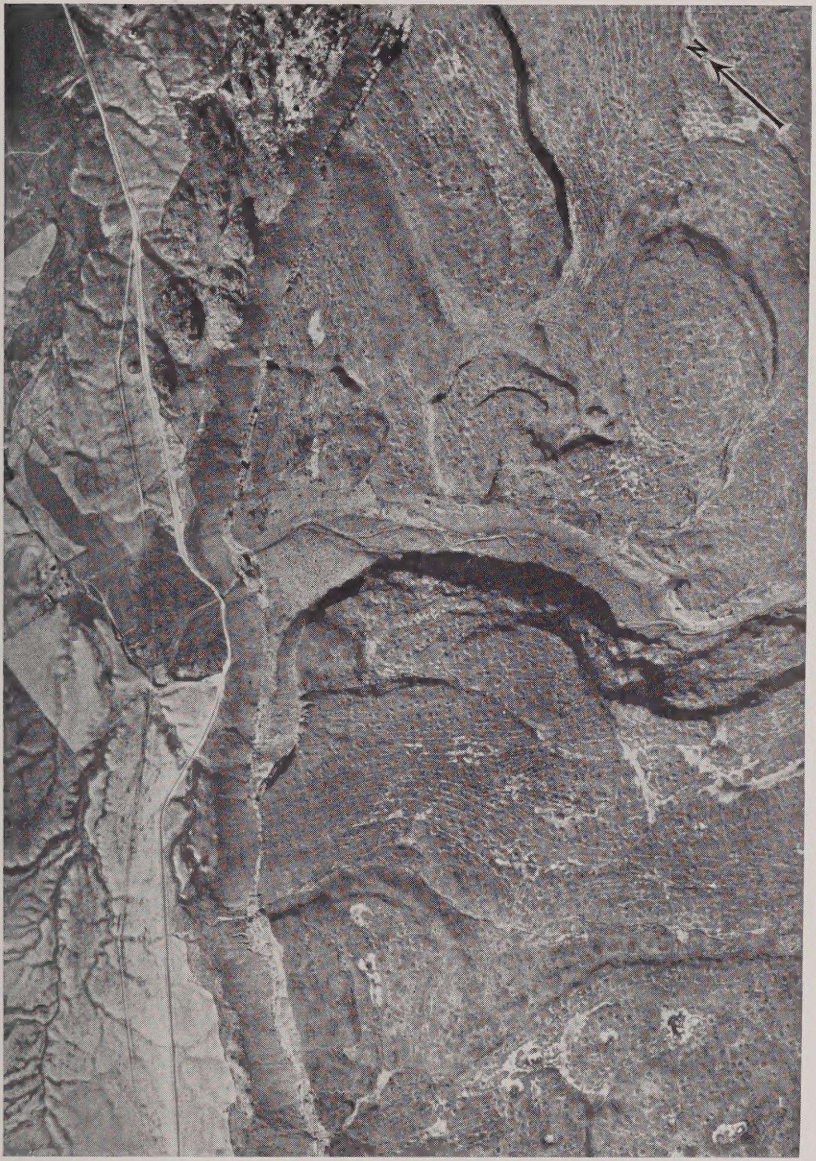


FIG. 32—The hanging tributary canyon of Martin Falls, upper Grand Coulee. The coulee floor, with light-hued, gullied silt cover, occupies the left third of the view. The coulee wall crosses from bottom to top. Summit scabland above the wall is well shown. A channel leading to the brink of the cliff hangs more than three-fourths of the total cliff height above the floor. A cataract exists here during the spring thaw. Figure 5 shows this from the coulee floor. Granite hills lie between road and coulee wall, near the top of the view. (Mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 118–121, U. S. Geological Survey.)

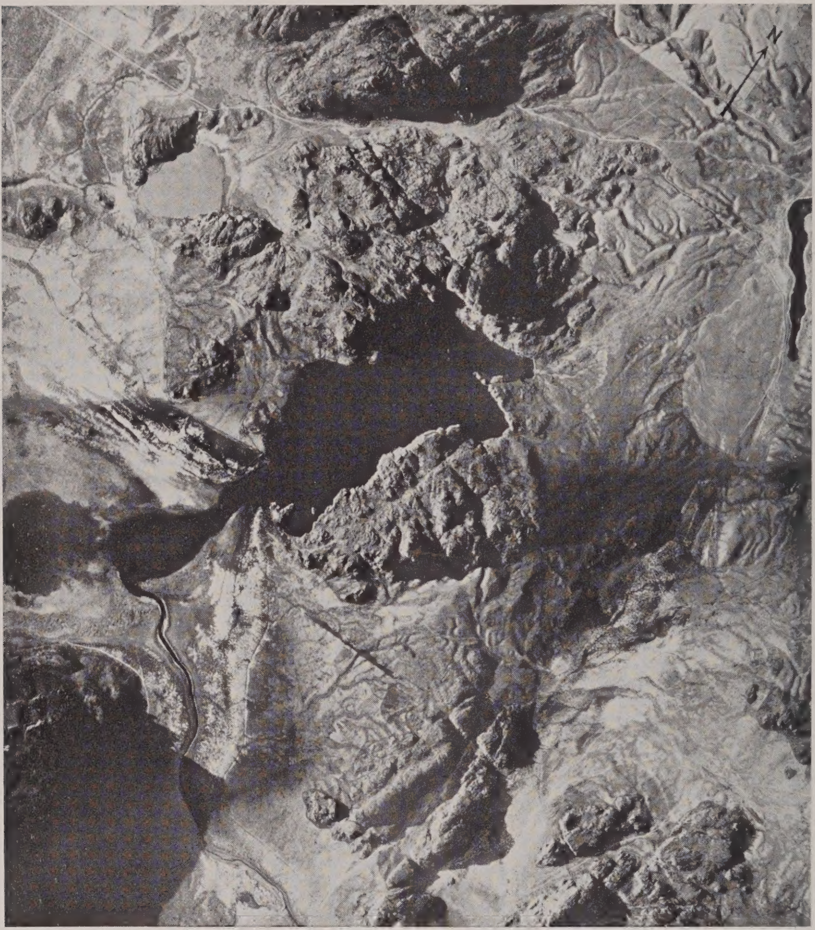


FIG. 33—Devils Lake and granite hills, upper Grand Coulee. Shadows fall to the lower right. The northern salient of Steamboat Rock appears on the left edge of the view, its summit about 850 feet above the lake. The granite hill at the northwest corner of the lake is 605 feet above the lake, and the one on the east is 410 feet above it. This is a part of the row of hills that so strikingly constricts the bottom of the coulee. (Mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 196–200, 216, 217, 219, 242, 244, U. S. Geological Survey.)

STAGES OF CATARACT RECESSION

For eleven miles of recession the fall maintained a nearly constant width and height. This implies a fairly constant volume for the glacial stream. The plunge pool elongated as the fall retreated, and probably part of its present fill was then made. Lateral cataracts and channels along the

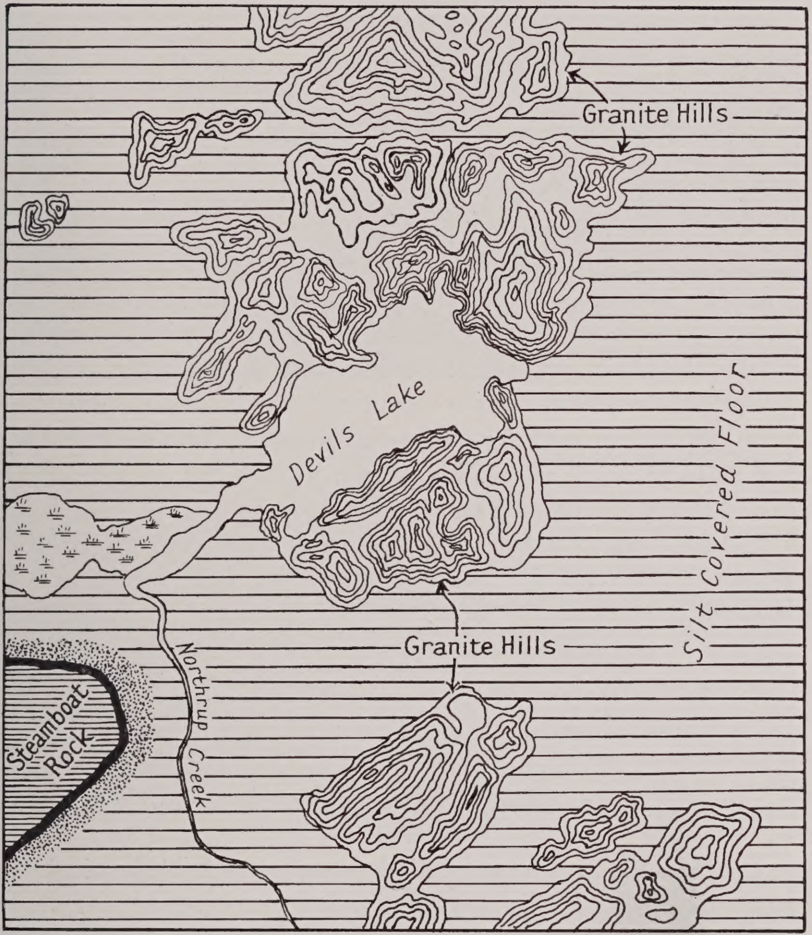


FIG. 34—Line drawing from Figure 33. Note the two sets of joints cutting the granite and the way erosion has bitten into the rock along them. The nearly north-south set approximately coincides with the course of several gashes as deep as the present silt floor of the coulee. Five of these are utilized as road or trail routes, and one contains Devils Lake. The main road of the upper Coulee, after crossing Northrup Creek, traverses one of these gashes for more than half a mile. The gash, known as Lovers Lane, is 150 to 200 feet deep and doubtless is a product of the glacial stream, not a pre-basalt feature. See Figures 35 to 37.

eastern cliff summits were abandoned, as was also the upper scabland, as the falls retreated northward (see Figs. 4, 5, 28, 30, and 32). How long a time was involved is unknown. It may have taken two or more glaciations, Columbia blockades, and consequent detours across the Waterville Plateau. Huge as this cataract was, it is conceivable.

Then changed conditions were encountered. The cataract broadened to the almost unthinkable width of five miles; and great lateral falls developed, some of them Niagaras in size. There was no change in height of falls and consequently none, by this factor, in the excavation of the plunge pools. There was no change in the character of the rock. There was no change in the preglacial topography across which the stream flowed, the cliff brinks recording the same upland as farther south. The only workable suggestion seems to be that there was an increase in volume, the glacial Columbia swelling to a river without comparison in the world today. The greatly widened upper scabland fits this idea, and the great increase in number and size of lateral falls supports it. The buried granite hills (Figs. 33, 35, 36, and 37) came to light as the more easily plucked basalt was removed. Lacking closely jointed structure, they survived the attack of the plunging waters and were fairly safe after the excavating mechanism had passed them.

Niagara's Variations in Cataract Width

The gorge below Niagara Falls is well known to have wider and narrower places. Cataract width has been the dominant factor in determining gorge width, though locally other causes are indicated; and cataract width[12] has changed five times during the recession of the falls because of volume variations in the river. The volume changes have ranged from 15 per cent of the present up to that as 100 per cent. Niagara, when but 15 per cent of the present volume of water, was carrying only the overflow from Lake Erie, the three large upper lakes then discharging elsewhere. Fifty measurements of width at the top and the bottom of the gorge (omitting stretches where local factors were important) indicate that the wider stretches are not quite twice the width of the narrower ones. A more than sixfold increase in Niagara's discharge produced less than a twofold increase in cataract width, increased depth and velocity taking care of the rest.

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[12] E. M. Kindle and F. B. Taylor: Niagara Folio, *Geologic Atlas of the United States No. 190*, U. S. Geol. Survey, 1913.

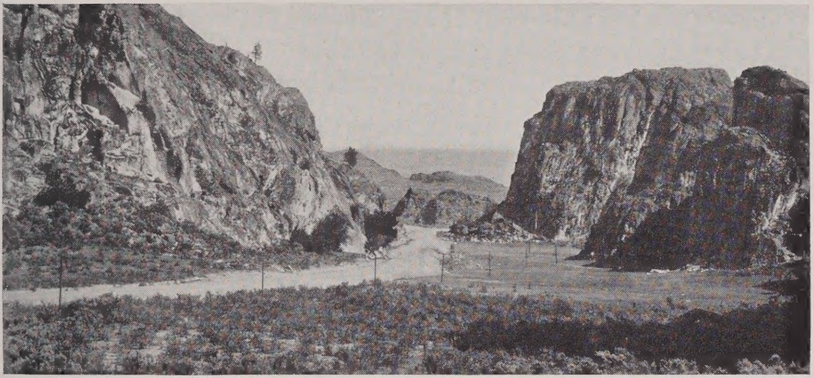


FIG. 35

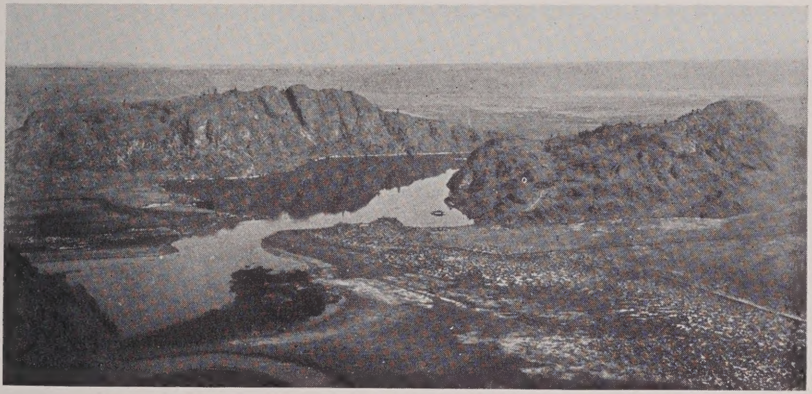


FIG. 36

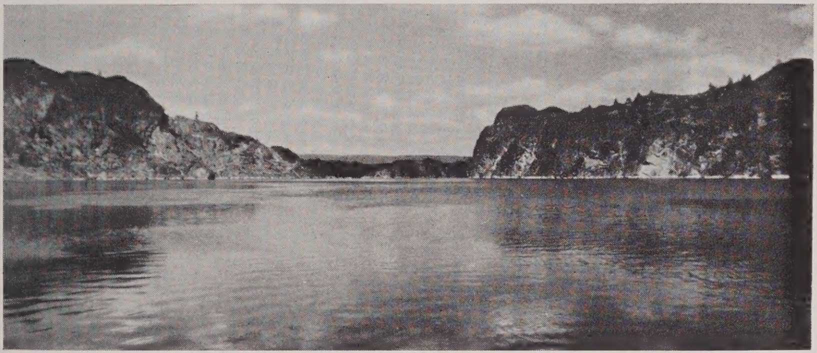


FIG. 37

FIG. 35—Channel between granite hills (Lovers Lane), upper Grand Coulee, looking north. (Photograph by Simmer.)

FIG. 36—Devils Lake from summit of Steamboat Rock, looking north. Compare with Figure 33.

FIG. 37—Devils Lake, upper Grand Coulee, looking north. The steep slopes on the west rise 540 to 600 feet above the water, and the cliffs on the east 220 feet sheer. (Photograph by DeLong and Drake.)

Niagara's variations in cataract width with volume discharge may be used as a suggestion of the inferred volume increase in Grand Coulee river. Steamboat Rock cataract, at its narrowest, was three times as wide as the one that made the first eleven miles of the upper coulee. If the Niagara ratio is only arithmetical, it suggests that the volume of the Grand Coulee river was increased twelve times. No account is taken of the great lateral cataracts in this computation, and the ratio is more probably a geometrical one.

The conditions giving rise to the Steamboat Rock cataract persisted while ten miles of recession was achieved. Then they disappeared, the cataract narrowed, and in its further recession, about two miles, it left a canyon of the same width as that made before the great flooding (Figs. 22 and 23). When this reached the walls of Columbia Valley, its crest lowered for the first time in the coulee's history, and the fall gradually disappeared. No plunge pool being carried through to the Columbia Valley, a continuous rock floor outcrops across the coulee at the head.

With the disappearance of the falls came a lowering of all glacial water in the Columbia Valley east of the coulee head, a condition to which the Erie basin may come at some time in the future. At several places along Niagara Gorge abandoned lateral cataracts are known. "American Falls" will eventually be added. Abandoned river floors above the gorge rim are now known, and more will appear as the cataract retreats. The débris-filled elongated plunge pool now constituting the gorge bottom will become longer but will die out where the falls incise the basin rim. Perhaps a future Goat Island will develop between two more nearly equal cataracts than the present ones and, by their retreat, will be left in mid-gorge like Steamboat Rock. In this comparison, the Lewiston escarpment is homologous with the Coulee monocline.

A greatly increased discharge over the upper coulee falls requires an equally great increase in the river through the narrow gorge below the falls. One might anticipate that this must mean undercutting of the walls along the narrow gorge and a final width exceeding that of the cataract whose retreat made the gorge. The narrowing at the northern end of the coulee, which never carried the flood through it, should be more marked than the eleven-mile stretch below the flood-stage cataract.

This difference in width does not exist, and there is evidence that no widening has occurred in the eleven-mile stretch. Along the base of the western wall of the gorge are places where rugged ledges of basalt project out into the silt-covered floor and carry excellent plunge-pool basins. They lie close to the foot of the wall. They seem to be the product of plunging waters along the margin of the upper coulee cataract. If such, they would be the first to vanish if the gorge were widened subsequently.

Survival of lateral cataract alcoves along the eastern wall of the narrow gorge might be considered further evidence. But an alcove notched well back into the main wall could be shortened by coulee widening without recording the fact. The survival of lateral cataract niches means only that widening, if it has occurred, was not as great as the original length of the subsidiary gorge.

Niagara may be appealed to again. Its augmentation to six times the former volume did not destroy the record of an earlier much smaller volume. There seems to be no tendency among students of Niagara to consider that any recognizable gorge widening has occurred because of increased volume of the river. Gorge width is a consequence of cataract width. Lateral excavation in a rock channel appears to be of minor importance.

Lower Grand Coulee

Before further considering the inferred great increase in the discharge of Grand Coulee the lower coulee will be examined. It should afford facts by which the inference can be verified.

The first glacial spill over the Coulee monocline found a dischargeway southwestward through the synclinal prolongation of the Hartline Basin. A consistent structural

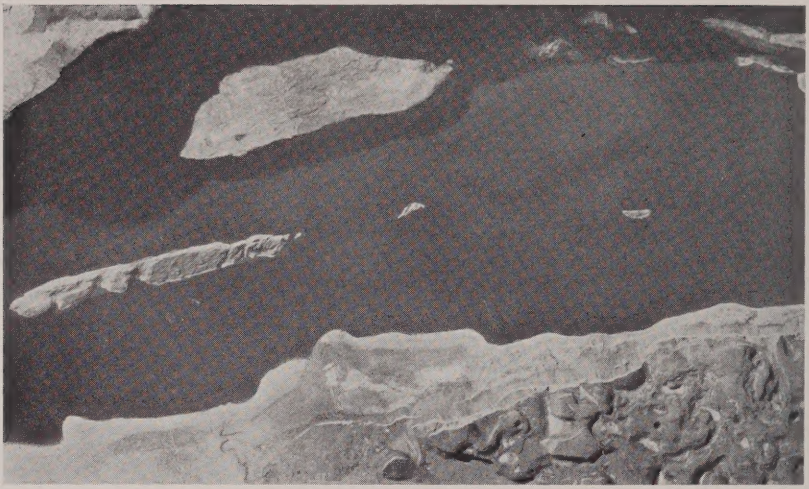
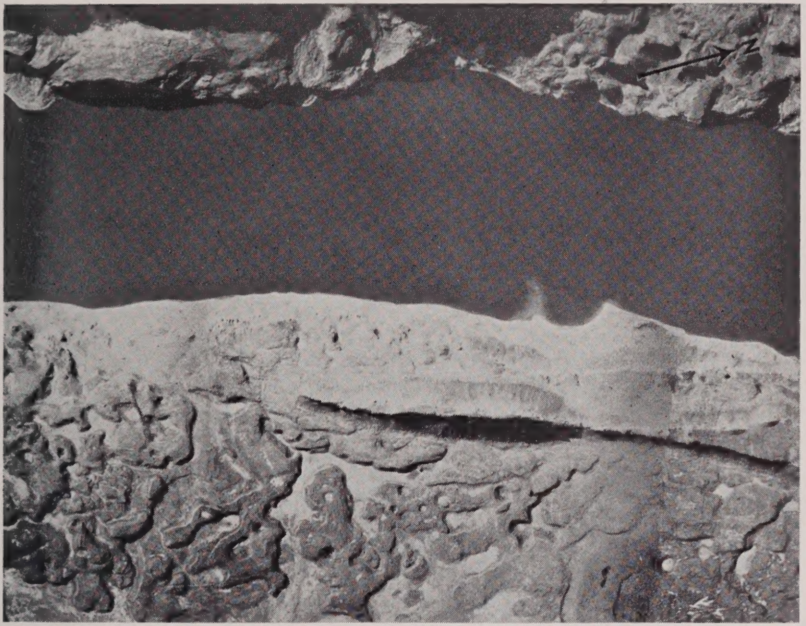


FIG. 38 (pp. 62 and 63)—Part of Lake Lenore, lower Grand Coulee. Cliff shadows fall to the northeast. About three miles of the length of the lake is here seen. Only the lower scabland ledges of the western wall are shown. Compare with Figure 42. The butte-and-basin scabland above the eastern cliff ranges up to 350 feet above the lake. The Great Blade is a hundred feet higher still. A hogback island records the monoclinal structure. (Mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 2–9, U. S. Geological Survey.)

descent of the synclinal axis supports this statement. Furthermore, a part of the preglacial valley here is still identifiable from the relations of minor tributaries above the scabland upper limits.

This glacial stream was confined to the synclinal drainage way and entered Quincy Basin at the site of Soap Lake. None of the remarkable distributary canyons of the lower coulee then existed or were needed. There was ample capacity within the limits of the structural valley.

Between Lake Lenore and Soap Lake this preglacial drainage way left Hartline syncline and crossed a low place in High Hill anticline. It entered Bacon syncline where Soap Lake now lies, on a floor probably at least two hundred feet higher than the existing lake surface. The glacial river across High Hill anticline was too large for the preglacial valley and found a steeper gradient than it needed. It began undercutting the columnar basalt and early initiated a low waterfall. This may have been entirely subfluvial like Celilo Falls, in the Columbia, at high water today. The



Soap Lake fall retreated across the anticline and finally into the southern end of Hartline syncline where it stands abandoned today.

A large remnant of the synclinal drainageway is easily recognizable north of this fall and east of Lake Lenore. It lies parallel to the lake and less than a mile distant. Though it is now pronounced scabland, its preglacial tributaries from the east do not hang more than a hundred feet above its floor. North of the transverse, and later Lenore Canyon, its course is problematical.

The most peculiar topography of the lower coulee is in that part containing Lake Lenore and the remnant of the preglacial synclinal drainageway. The lake occupies part of the canyon eroded *in* and *along* the monocline. Its surface is less than 1100 feet above sea level, its depth is unknown. The floor of the synclinal valley remnant is considerably higher, ranging from 200 feet above the lake at the south end to nearly 400 feet at the north end. Both channels are strongly marked by scabland features but notably different

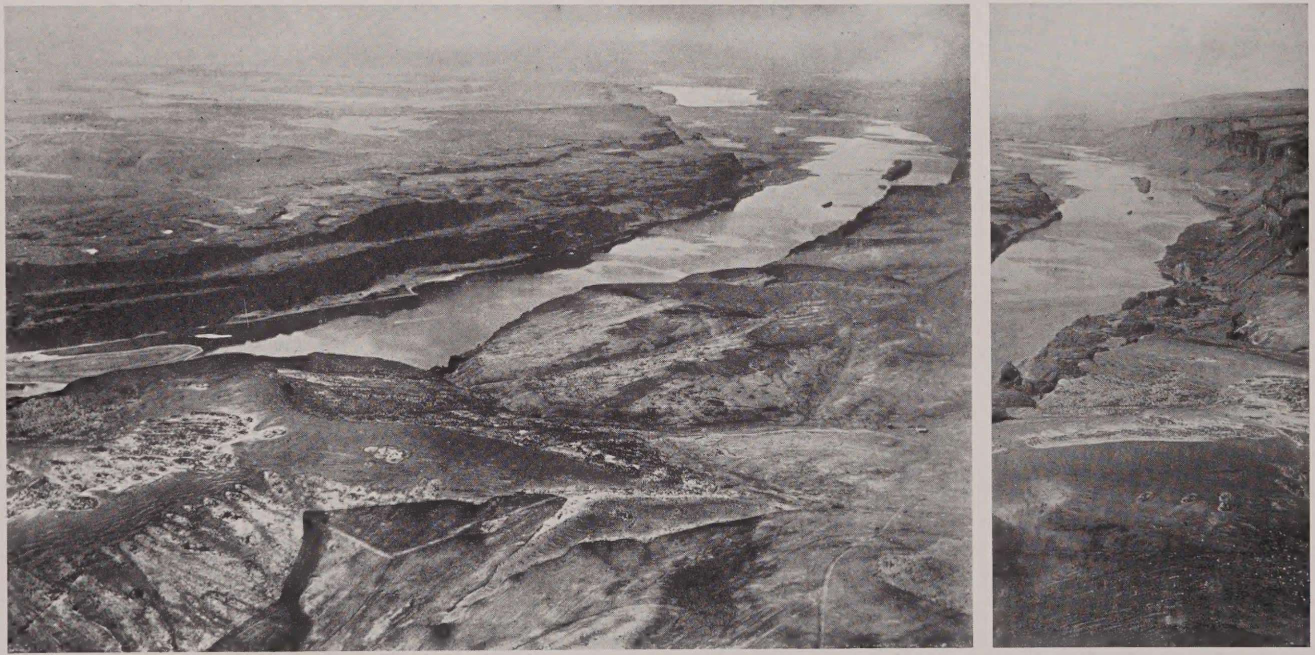


FIG. 39—Synclinal and monoclinal channels, lower Grand Coulee. The pictures are from two slightly different viewpoints, juxtaposed to make a composite. The observer is looking southeast from an altitude of about 1500 feet above the lake. The high places on the median ridge may be remnants of preglacial divides between gulches that crossed the site of the ridge at the sags in its crest. (Oblique aerial photographs by Libby & Son.)

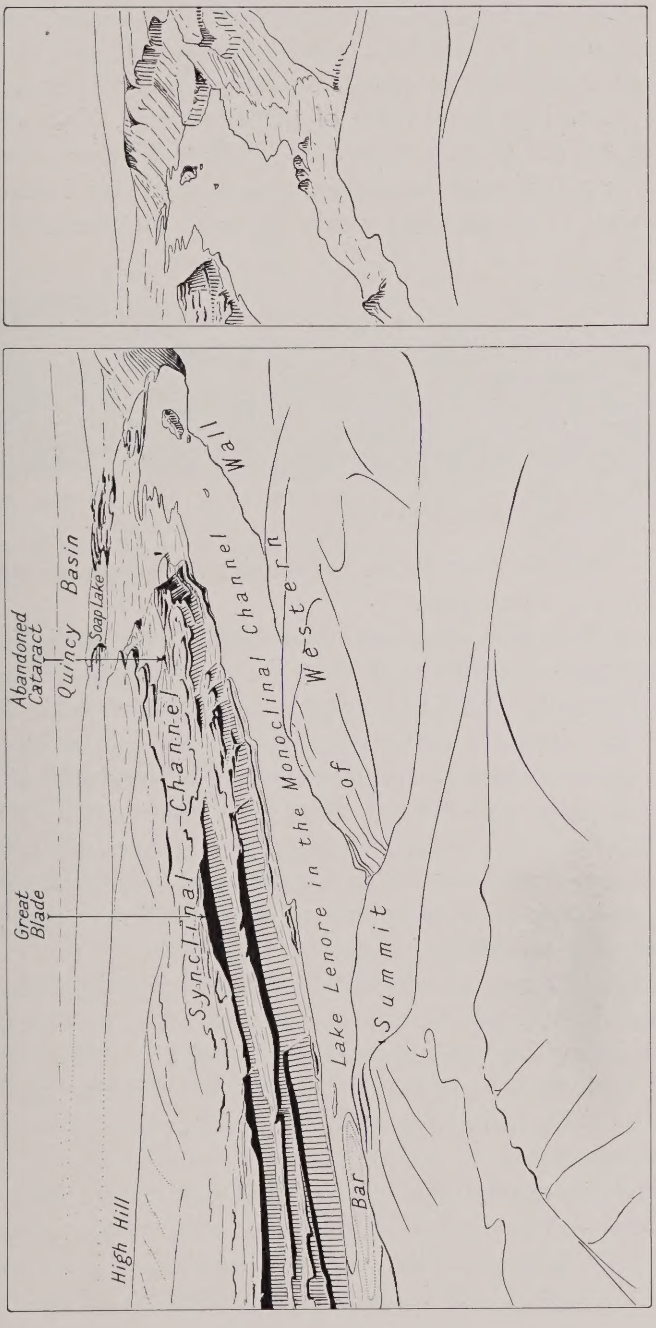

Abandoned Cataract
Great Blade
Quincy Basin
Soap Lake
High Hill
Synclinal Channel
Lake Lenore in the Monoclinal Channel
Wall of Western Channel
Summit
Bar

Fig. 40—Line drawings from Figure 39.

in character. The higher eastern channel has cataract ledges across it 50 to 75 feet high, rock basins in its floor 100 feet deep, and a maze of minor anastomosing channels and buttes. Figures 38 and 39 show some of these features. The deeper lake channel has great longitudinal cliffs and ledges, likewise with strong scabland expression, and hogback islands of tilted basalt (Fig. 43) that would be buttes if the lake were drained. But no transverse cliffs exist anywhere along the canyon in the monocline.

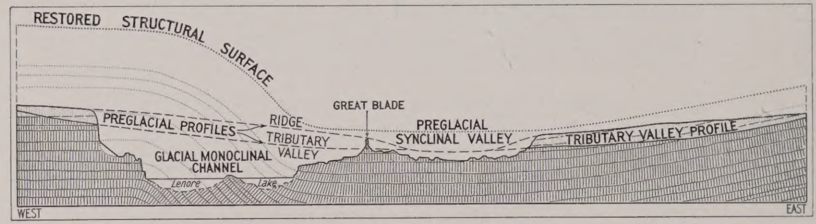


FIG. 41—Diagrammatic cross section of lower Grand Coulee to show relations of preglacial valleys and glacial channels, looking northward.

East of the higher channel are normal tributary drainageways, unquestionably antedating the scabland and hanging a little above it. West of the lake channel (the main lower coulee) are similar forms, away up on the slope, hanging several hundred feet above the lake. Their profile, if continued out into the canyon from the great western wall, would intersect the present surface *east of the lake canyon.* They were not tributaries to a preglacial valley along the main coulee route: they belong to the synclinal valley, the higher eastern member of the double spillway.

Between the two parallel scabland channels is a sharply expressed ridge (Figs. 38, 39, 41, and 42), a greatly elongated scabland butte, its summit locally 250 feet above the eastern channel and 450 feet above the lake. The highest place on this cliffed ridge is literally a blade of rock, unscalable except at the south end.

Let it be repeated that the main lower coulee has been dug in and along a belt of tilted flows that preglacially was a hillside, the greatest of the region. The dipping flows appear now chiefly as hogback islands, both walls consisting largely of horizontal flows. The western wall here and there shows remnants of the highest part of the flexure, and the eastern wall (rising from the lakes) locally shows the lowest part, leveling out for the synclinal floor. Structure, altitude relations, hanging tributaries—all testify that the eastern or synclinal channel is on the preglacial course and that there was *no* monoclinal channel before glaciation.

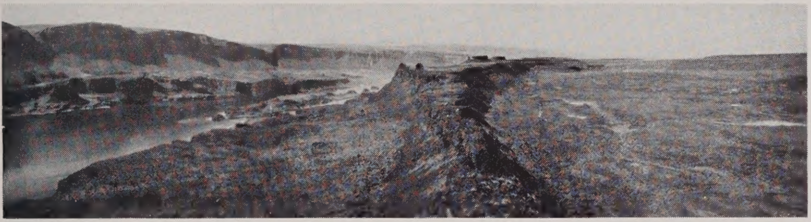


FIG. 42—Ridge between the monoclinal and synclinal channels, lower Grand Coulee. Looking north from the Great Blade. The lake surface is about 250 feet lower than the synclinal channel floor, and the ridge is about 75 feet higher. Hanging valleys west of the lake were once continuous across both lake canyon and ridge to the synclinal channel.

Nor was a monoclinal canyon channel developed during the first stage of glacial discharge. While the upper coulee cataract retreated eleven miles from the monocline, the eastern channel here carried all the water to Quincy Basin. Its western margin may have been somewhat west of the median ridge now dividing the two spillways. But the flexed and broken basalt in the monoclinal slope was safe from attack. Its outcrop was higher than the glacial river surface.

Then occurred that unbelievable increase in volume. Many times as much water came roaring down the spillway. It rose on preglacial slopes hitherto unattacked, and those on the west proved exceptionally vulnerable. Scabland making was everywhere largely a matter of plucking. The broken basalt in the monocline yielded to the impetuous assault more readily than did basalt in nearly horizontal positions. The monoclinal belt became a place of excessive channel deepening. Every foot of deepening meant that much greater depth of surging water, for this was *channel* erosion, not valley erosion. Whatever the life of the stupendous cataract at Steamboat Rock, it covered also the complete shifting of the lower coulee over into the monocline. Episodes like this seem fantastic inventions, but what else shall we do with the field evidence? The formula "less water and more time" never will account for Grand Coulee features.

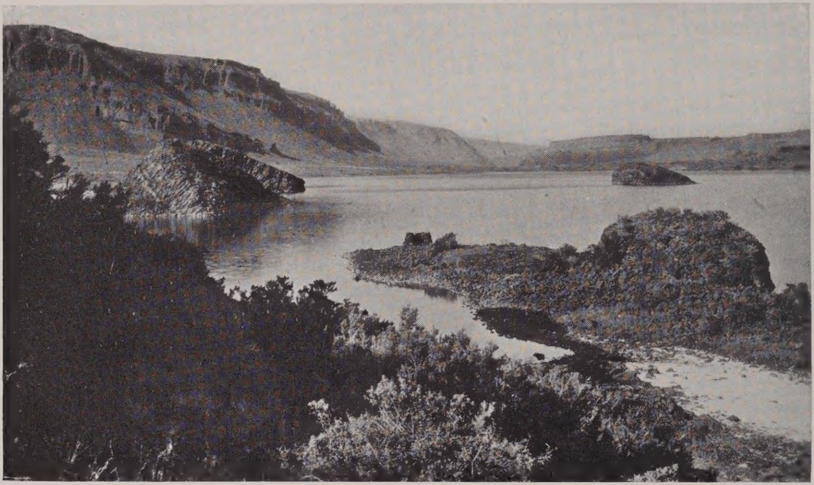


FIG. 43—Lake Lenore, lower Grand Coulee, looking north. Part of the monoclinal structure shows in the western wall and as a small hogback island. (Photograph by Simmer.)

With the arrival of the great flood, the entire distributary system of Grand Coulee sprang into existence. A huge swirl of water flooded eastward from Coulee City into Hartline Basin, dragging gravel more than 250 feet up from the coulee floor and depositing it with upslopes in downstream directions, burying older gravel and older loess, producing bar fronts 30 to 40 feet high that face away from the coulee and foresetting the débris everywhere away from the coulee. Most of High Hill anticline was completely denuded and its summit scabland made by water which, by bottom gradients, had to rise 250 feet or more to flow across it. The striking bars pendant from the southern slope of the anticline are part of the record of this enormous flood. So are the deeply cleft canyons which, descending against the structural-topographic dip slope of the northern limb, cross the summit and gash its southern slope. Lenore Canyon either was cut entirely or became very greatly enlarged by a part of the distributary flood. Spring Coulee and Dry Coulee suffered great erosion. The cataract previously developed north of Soap Lake was carried back to its present location during the catastrophic denudation. At this time it certainly was subfluvial, for a bar along the eastern edge of the channel above the fall continues with unlowered summit level past the cataract cliff to flank the deeper canyon below the fall.

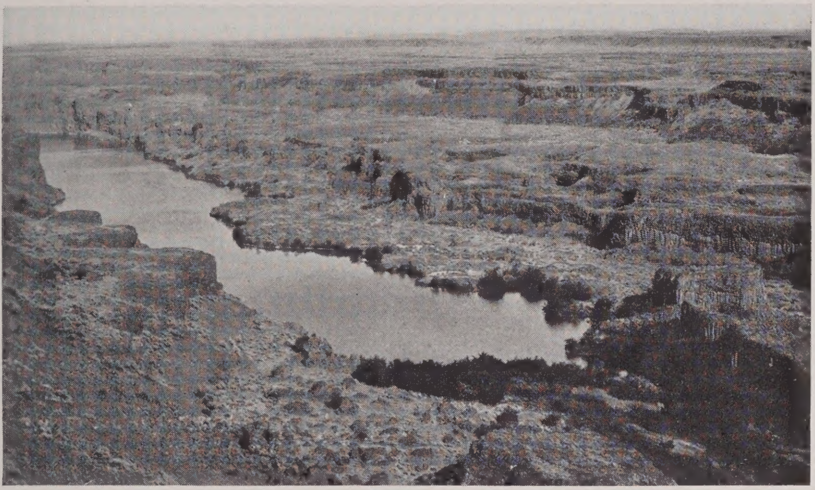


FIG. 44—Deep Lake, great cataract group, lower Grand Coulee, looking southeastward from a cliff north of lower end of the lake. The pothole-covered ledge is beyond the lake. The scabland summit of High Hill anticline constitutes the sky line. (Photograph by Simmer.)

Perhaps the monoclinal trench was eroded by cataract or cascade mechanism,[13] though that seems rather unlikely. Adequate structure and integrity of rock were lacking for waterfall retreat in the disturbed belt. More probably the lake-filled trench was eroded simultaneously throughout its length. Its lack of a bottom gradient appears to be of little significance here. Surface gradient of the mighty discharge alone was essential. The lower coulee has no definite cataract niches to record entrance of water into it from the eastern higher channeled scabland. There is, instead, a clear record of discharge out of it during most of its deepening.

The great cataract group south of Coulee City (Figs. 7, 8,

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[13] O. E. Meinzer: The Glacial History of Columbia River in the Big Bend Region, *Journ. Washington Acad. of Sci.*, Vol. 8, 1918, pp. 411–412.

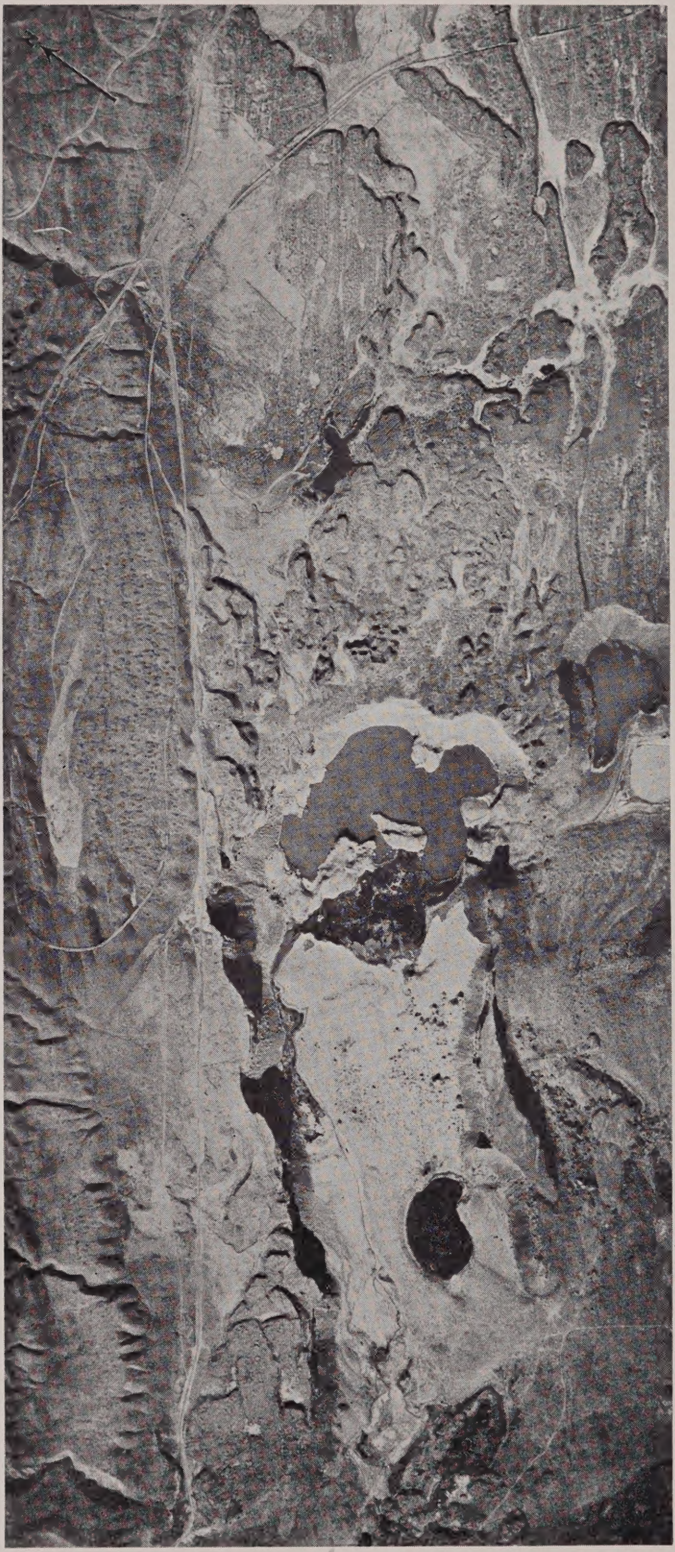

FIG. 45—Dry Falls portion of the great cataract group, lower Grand Coulee. Shadows occur only on east-facing cliffs. Other cliffs are identifiable by their talus zones. Fall Lake is bordered on the northeast by the cataract cliff, 400 feet high except where a deeper channel enters it at the north. The western part of the lake basin has been filled in by a swamp. The smaller eastern alcove, close to the margin of the picture, contains both a lake and a swamp. Above the cataract brink is butte-and-basin scabland channel bottom with a maximum relief of 100 feet showing. (Mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 26–30, U. S. Geological Survey.)

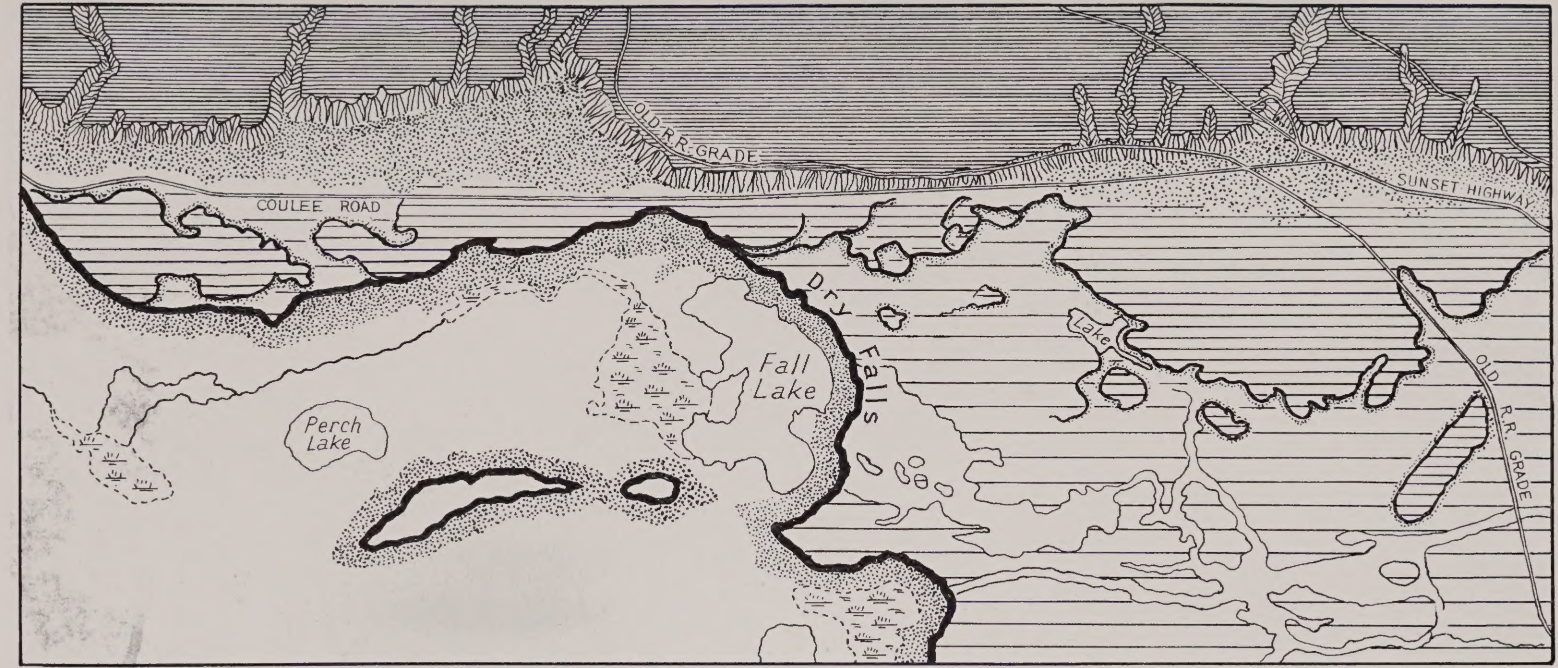
OLD R.R. GRADE
SUNSET HIGHWAY
COULEE ROAD
OLD R.R. GRADE
Lake
Dry Falls
Fall Lake
Perch Lake

FIG. 46—Line drawing from Figure 45. The road along the lower coulee follows close to the northwestern edge of the channel features. Channel floor older than the alcove lies between this road and the recess floor at the southwest end of the picture. Lower slopes of the monocline above the channel level, with normal erosion forms, show along the edge northwest of the alcove. Note the blade-like "Goat Island" between the two alcoves. Compare with Figure 10.

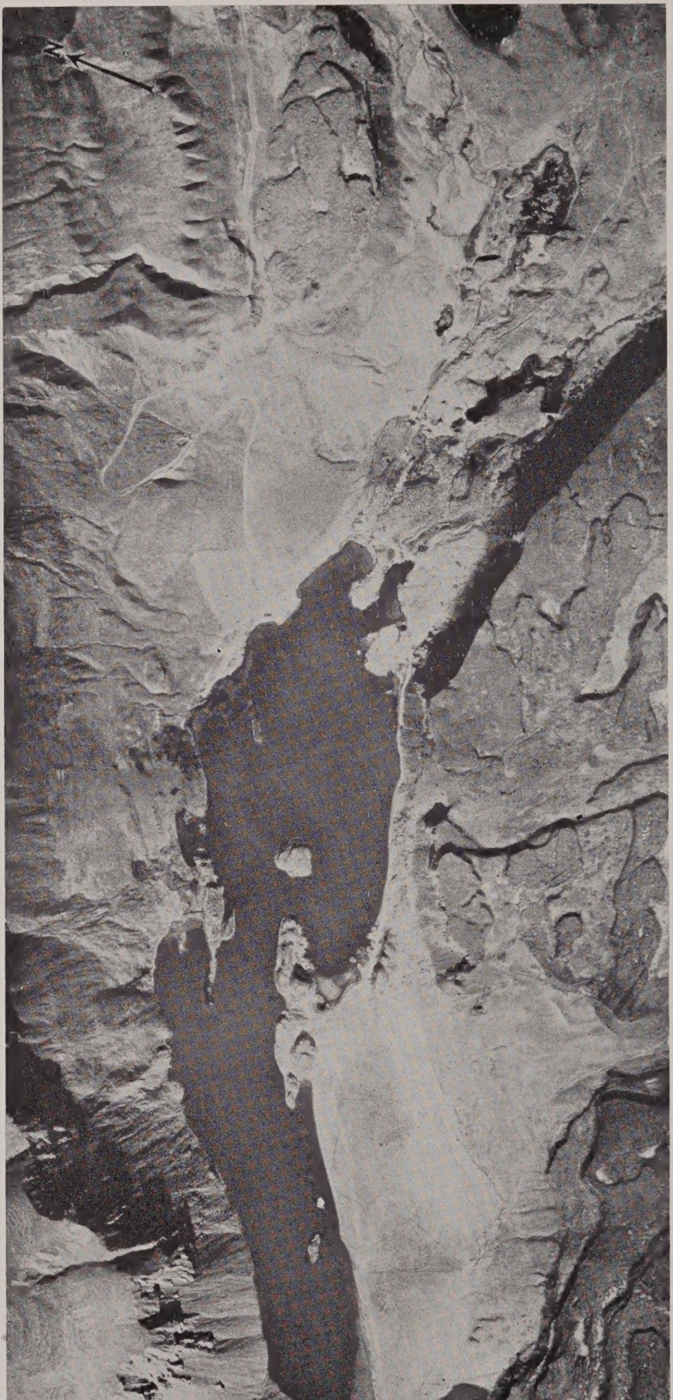

FIG. 47—Park Lake, lower Grand Coulee. This view overlaps with two others: the head of Blue Lake (Fig. 13) is on the left, the lower end of Dry Falls alcove (Fig. 45) on the right. The western cliffs carry a remnant of the monoclinal slope near the western end of the lake. (Mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 21–25, U. S. Geological Survey.)

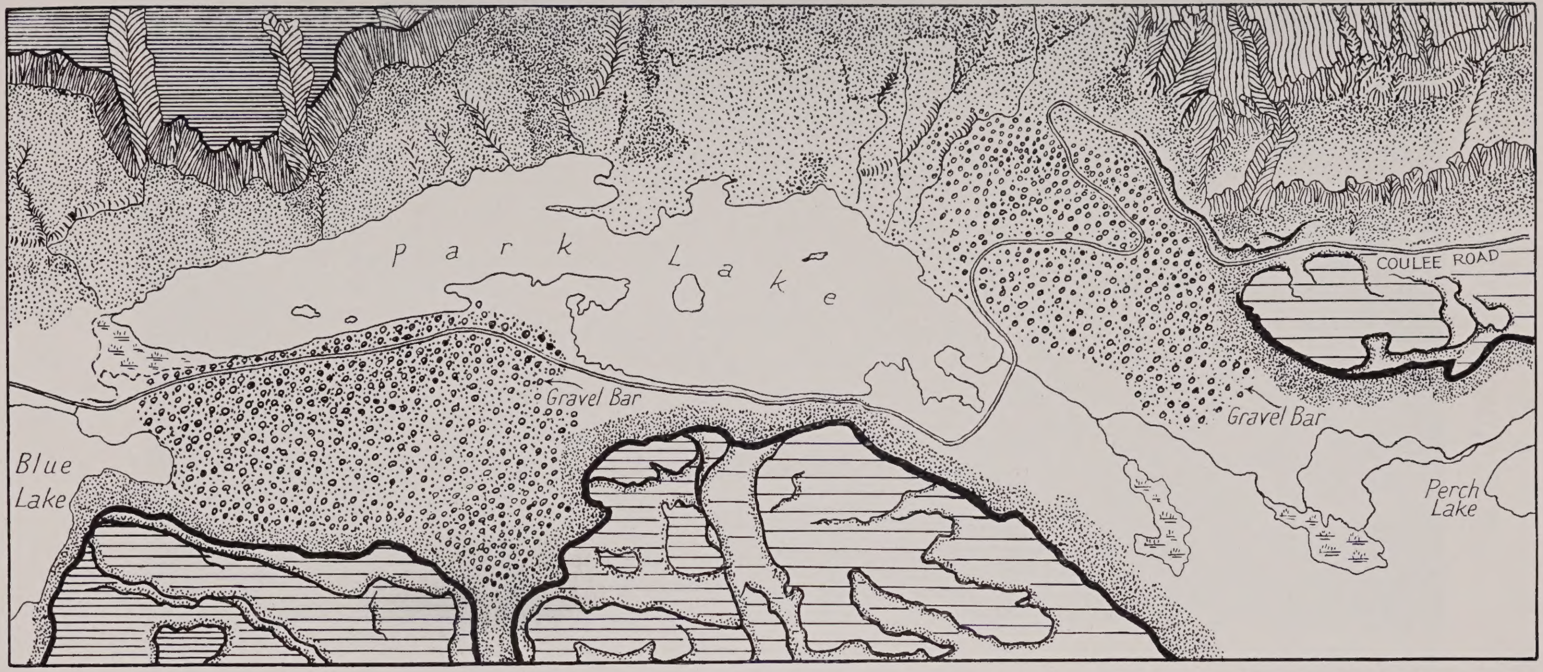
Park Lake
COULEE ROAD
Gravel Bar
Gravel Bar
Blue Lake
Perch Lake

FIG. 48—Line drawing from Figure 47. Hogback islands record the structure in mid-width. The monocline strikes into the wall at the highway serpentine between the lake and the brink of the falls. The butte-and-basin scabland on the eastern summits, 400 feet above the lake, was glacial river channel bottom before the lake canyon was cut. Park Lake is 150 feet deep.

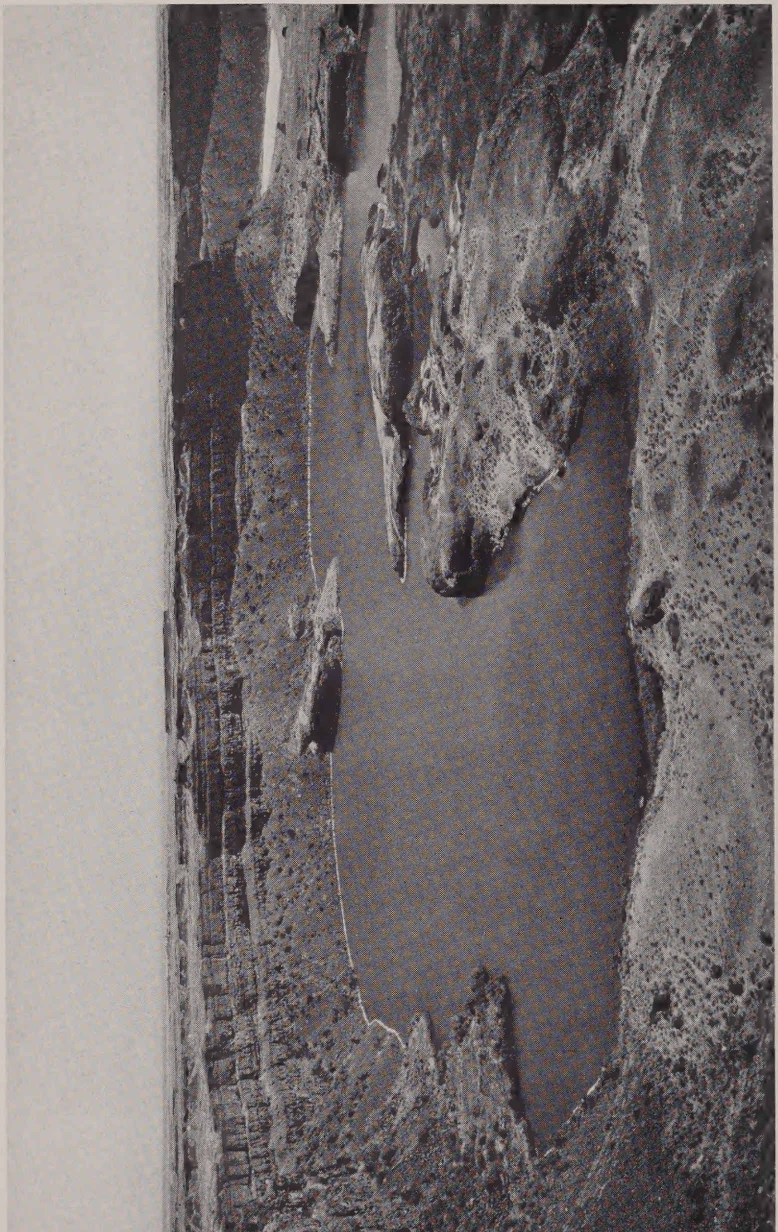

FIG. 49—Fall Lake, great cataract group, lower Grand Coulee, looking northeast from Vista House in Dry Falls State Park. The lake is 380 feet below the camera. The cataract cliff has a maximum height of 400 feet above the lake, whose basin is 80 feet deep. The white area near the right side of the view is a desiccated lake flat in the eastern of the two recesses of Dry Falls. (Photograph by Frank Guilbert.)

10, 45, 46, 49, and 50) seems to need such a flood for its making. It is 3¼ miles wide, and probably all members functioned at one time. It had to wait, however, until the monoclinal trench was well excavated, and it originated probably no farther downcoulee than the head of Park Lake. Maximum retreat, therefore, was not more than five miles, an item consonant with its late appearance in the episode. As it developed, the flood across Hartline Basin and across High Hill anticline was drained off, and the distributary system apparently was reduced to Lenore Canyon and Dry Coulee. Lenore Canyon is cut more than 200 feet deeper than the preglacial synclinal valley which it transects. The eastern channel along Lake Lenore therefore was abandoned about this time.

Then the flood ceased, as recorded by the narrowing at the head of the upper coulee. A normally proportioned glacial Columbia took its place, hardly sufficient to operate all cataract heads in the great group and probably inadequate to supply Lenore Canyon. The glacial river returning to the lower coulee found a new and much deeper course than the one it had previously occupied, though a part of the old course remained, 200 to 400 feet above the new and lying a mile offside.

Whence came the water of that great flood stage? Many have said that a prodigious flood to explain channeled scabland might seem more reasonable if an adequate source could be shown. But we accept as facts many geological records we cannot explain. Continental glaciation, which lay back of the flood, is yet to be satisfactorily accounted for, though today it is almost universally accepted as fact. The cause of the flood is not yet known.[14] When we understand its character better from the study of its effects, we may make progress in finding a satisfactory way to attack the problem of its cause.

That flood, however, was much greater than Grand Coulee

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[11] See the suggestion of bursting of a glacial lake dam in J Harlen Bretz: Lake Missoula and the Spokane Flood (abstract), *Bull. Geol. Soc. of America*, Vol. 41, 1930, pp. 92-93. Figure 14 embodies the same idea.

river at its maximum. Though the coulee is the most spectacular of all channeled scabland features, it did not carry half the water that swept across the plateau to make the scabland system. This was the Spokane Flood of the writer's earlier papers on scabland. Notable canyoning occurred in other places, but nowhere were the gradients and volumes so favorably combined for deep trenching as here.

As previously stated, the coulee is older than the moraine to the west. When the moraine was built, a glacial river again flowed through the coulee. And now ponded water in Columbia Valley needed to rise only to about 1600 feet above sea level to spill across the plateau. There is a widely distributed "white silt" in this valley and its tributaries above the head of Grand Coulee. It was clearly deposited during the retreat of the latest ice sheet. Its upper limits range between 1700 and 1800 feet, according to J. T. Pardee, who named it the Nespelem formation.[15] Though it was not known along the Columbia below the head of Grand Coulee, Pardee adopted G. M. Dawson's idea for similar silts in British Columbia valleys and read a regional submergence from the Nespelem formation. R. A. Daly had previously opposed this,[16] asserting that the white silt was deposited in glacial lakes.

It surely is a significant fact that the Nespelem silt continues with the same terrace summits out of Columbia Valley into Grand Coulee and along the upper coulee for its full length. Silt terraces at the head are about 1650 feet above sea level, and their surfaces descend to about 1570 near the site of the initial upper coulee cataract. But no silt like the Nespelem formation is known in the lower coulee or farther south along the route of glacial water. No general subsidence can be predicated if the silt occurs only back of the Okanogan dam and in the elongated basin of the upper coulee. A lake or a very sluggish river, held up by the scabland floor of Hartline Basin, seems to be required.

[15] J. T. Pardee: Geology and Mineral Resources of the Colville Indian Reservation, Washington, *U. S. Geol. Survey Bull. 677*, 1918.

[16] R. A. Daly: A Geological Reconnaissance between Golden and Kamloops, B. C., along the Canadian Pacific Railway, *Canada Geol. Survey Memoir 68*, Ottawa, 1915.

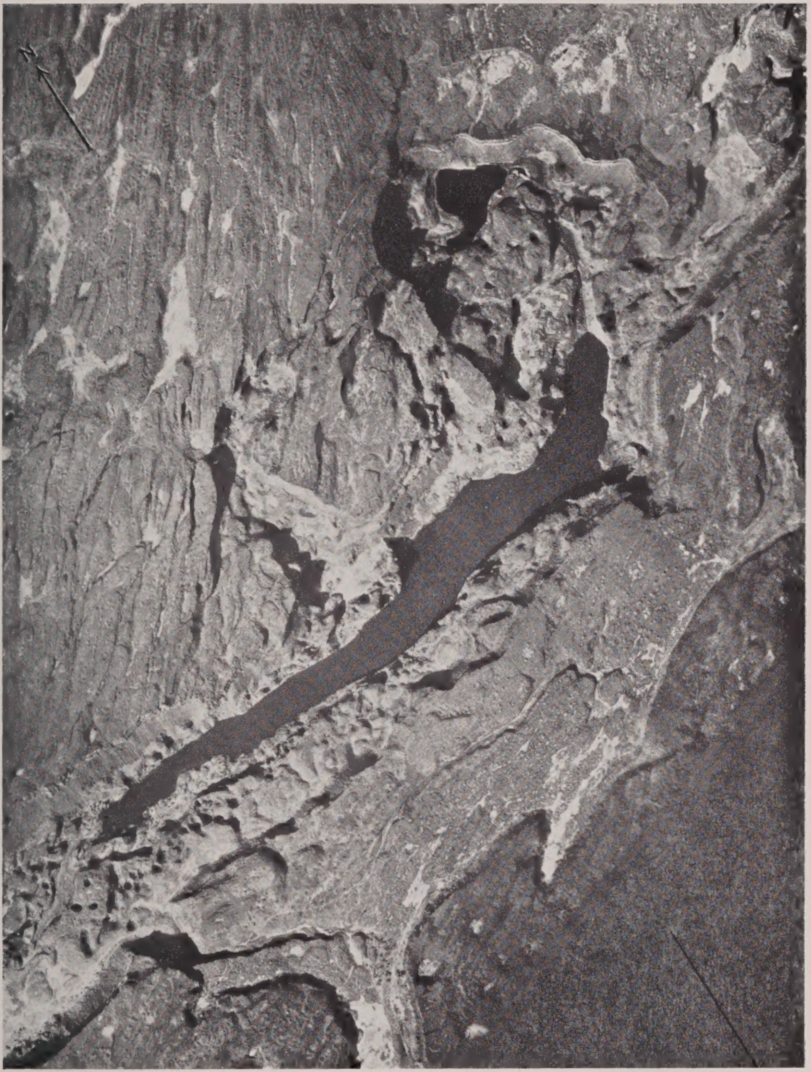


FIG. 50—Deep Lake, great cataract group, lower Grand Coulee. Cliff shadows are cast toward the upper right. Deep Lake, 1½ miles long, occupies part of the gorge left by cataract recession. Three major niches on the northern side have receded into the joint-featured scabland floor above the cataracts. Deep Lake is 350 feet below the lowest through channels shown on this floor. Castle Lake, in the largest niche, is 250 feet below. Note the pothole-riddled ledges south of Deep Lake. The ledges are 100 feet above the lake. Some of the holes are 40 to 50 feet deep. (Mosaic of aerial photographs, Grand Coulee Series, Nos. 160–168, U. S. Geological Survey.)

A channel in the silt of the upper coulee south of Steamboat Falls occupies about half of the coulee floor. It is a river channel, but it is also the elongated unfilled basin of this part of the coulee. If the silt terrace tops record a complete filling of the plunge pool north of the monocline, this channel records later erosion as the narrow trenches across the scabland floor near Coulee City were developed. But much of the terrace-margined channel is below the lowest of these trenches, and in the wide coulee about Steamboat Rock the closed basin is one to two miles wide and has very gently sloping sides not at all like channel bluffs.

An alternative explanation is that the coulee floor possessed moraine, bar, and terrace relief before the silt was deposited and that the silt only veneers this earlier channel relief.[17] The latest glacial Columbia, by this view, simply kept the old channel clear and deposited silt over surfaces below 1570 to 1650 feet where slacker water prevailed. Such a river would probably keep only the lowest or the Dry Falls alcove of the great cataract group in use and would not account for very much of its lengthening. A few large gravel bars rise above the silt terraces (see Fig. 51). They are older than the Nespelem silt and, by this view, they are portions of the channel floor which were too high to receive a silt cover.

Two dry deltas, illustrated in Figures 52 and 53, bear on the problem of the channel in silt. They lie at the foot of the western wall, projecting into the broad basin west of Steamboat Rock and within the loop of the supposed moraine on the coulee floor. Each delta is about 1640 feet above sea level, only slightly higher than the highest silt terrace in this latitude. The frontal slope of each is a scarp about 140 feet high. Neither shows any trenching since the disappearance of the water body in which they grew. Thus they are apparently not the product of ordinary storm water spilling over the coulee wall. The lowest place on the northern rim of the upper coulee basin is 1530 and on the southern rim

---

[17] In the writer's first paper on the scabland problem (Glacial Drainage on the Columbia Plateau, *Bull. Geol. Soc. of America*, Vol. 34, 1923, pp. 573–608) there is a brief description of a boulder bed beneath the silt of Grand Coulee.

1525 feet. These deltas therefore do not record any postglacial lake in the basin. Since the deltas could not grow out into the great stream below the retreating cataract, they must postdate the excavation of the coulee. They seem to be a product of meltwater during the latest glaciation of the plateau, built while the Okanogan lobe was wasting away on the summit scabland immediately west of the coulee. They also seem to testify to the sluggishness of the Nespelem Columbia.

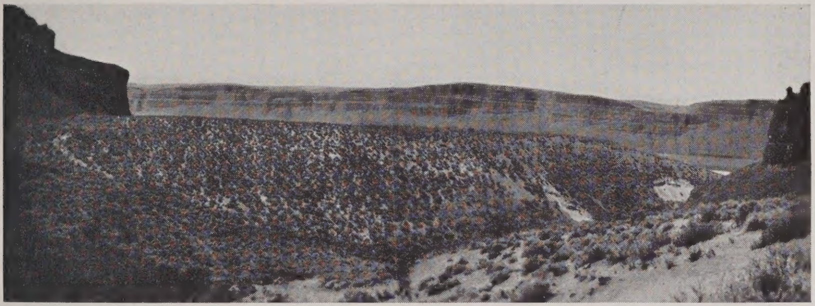


FIG. 51—Bar in lateral cataract recess, upper Grand Coulee. The view shows the back side of the bar, the broad fosse, and the narrow gully that has drained it. The western wall of the coulee is seen in the distance. Foreset beds in the gully scars dip to the right, up the coulee, recording an eddy in the alcove after the cataract had been abandoned.

The glaciation of Steamboat Rock occurred during the maximum advance of the latest ice sheet, a little before the silt was deposited. It may be that the upper coulee was entirely closed by the ice and that the Northrup Canyon group records a detoured glacial river, forced to use part of the upper scabland again and falling back into Grand Coulee just east of Steamboat. This interpretation encounters difficulty, however, in accounting for the orientation of the Northrup canyons. They clearly were supplied by water that left the main route immediately north of the initial Northrup cataract. Indeed, the western of the three canyons here heads back into Grand Coulee, notching the main coulee wall and semi-isolating a smaller Steamboat Rock (Figs. 2 and 5). It seems unlikely that a glacial dam in the head of Grand Coulee, having a contact of only a mile with the eastern wall, could have remained effective while the Northrup group was

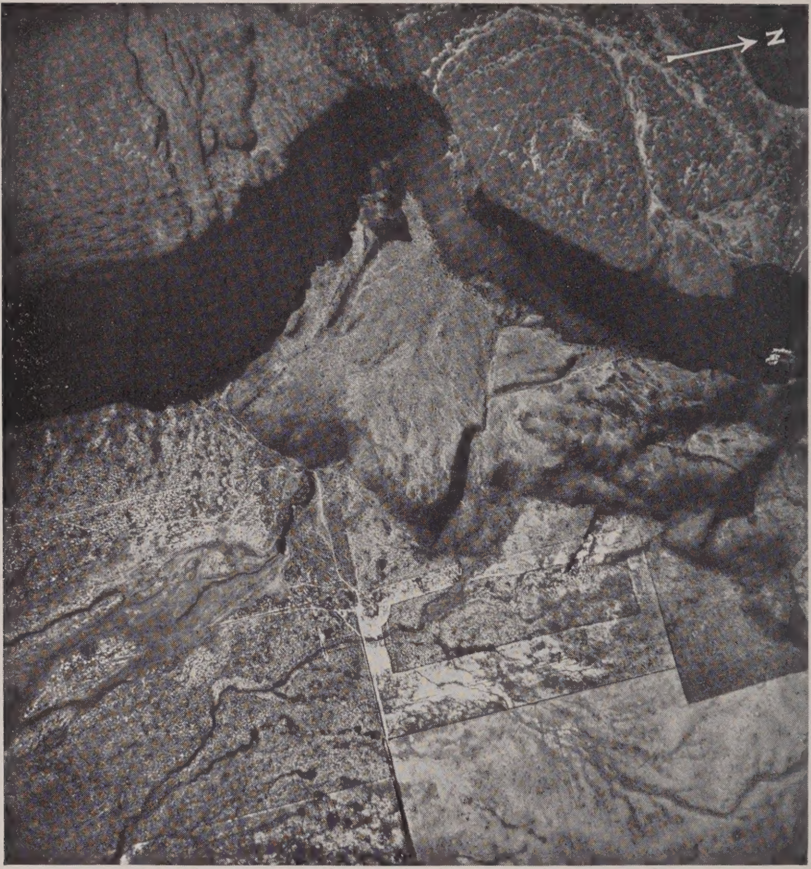


FIG. 52—Detail of the western wall, upper Grand Coulee. The scabland summit of the wall occupies the upper fourth of the view. The wall is marked by an amphitheater-like "tributary," with walls almost as high as the main coulee floor. The delta edge is 1640 feet above sea level. It lies directly west of the southern end of Devils Lake, in the broad silt-covered floor west of Steamboat Rock. (Vertical aerial photograph, Grand Coulee Series, No. 78, U. S. Geological Survey.)

excavated. Much more likely is it that Barker Canyon and Northrup Canyon are of the same age—products of the Spokane Flood.

The niche at the head of one of the deltas in the coulee (Fig. 52) suggests that some of these cataracts over the western cliff may date from the moraine-building glaciation, not from the earlier episode of great flooding. But certainly Northrup Canyon includes the only alcoves in the eastern wall for which this explanation has any plausibility. And

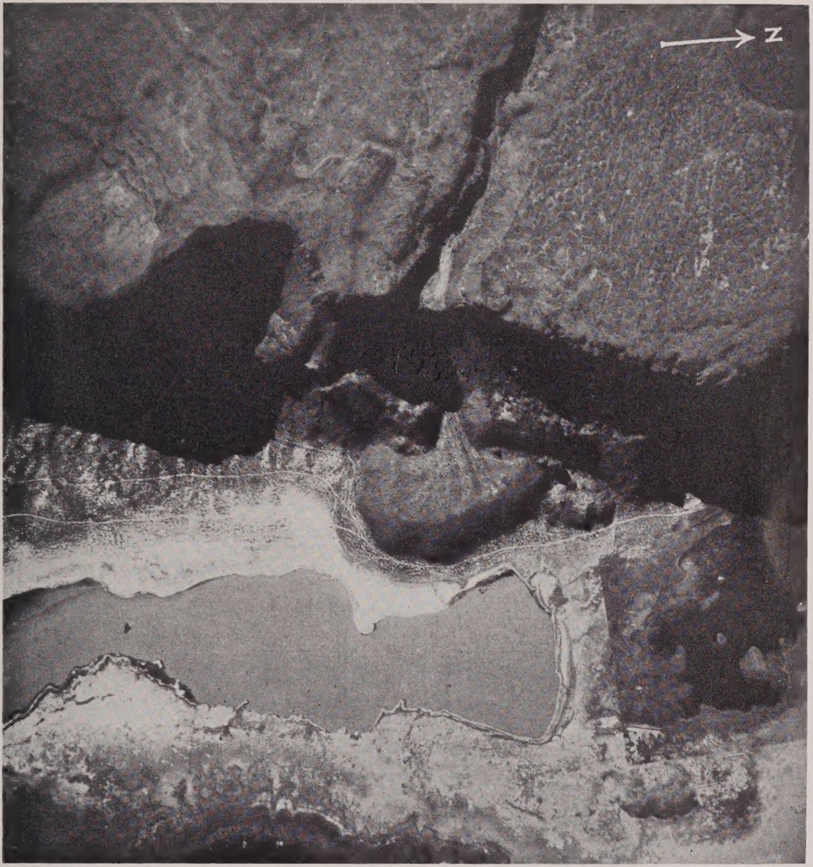


FIG. 53—Detail of the western wall, upper Grand Coulee. The summit scabland occupies the upper third of the view, the wall crosses from right to left, and its shadows encroach a little on the silt-covered floor. An ephemeral lake occupies part of the floor.

A lateral cataract niche hangs about halfway up on the wall, and a scabland channel without a pronounced niche crosses the scabland and hangs still higher. Below the channel mouth is a delta whose surface (1640 feet above sea level) is about 50 feet higher than the tops of silt terraces in this vicinity. (Vertical aerial photograph, Grand Coulee Series, No. 70, U. S. Geological Survey.)

certainly the remarkable absence of meltwater records (scabland or outwash) in front of the strong moraine west of Grand Coulee indicates a paucity of glacial streams during the wastage of the Okanogan lobe.

Again and again the writer has asked others and himself "Where is the dangerously weak point in the flood hypothesis?" One can stand on the brink of Northrup Canyon and aver with confidence that it can never be satisfactorily explained except as an extinct Niagara. He can look across to the scabland summit of Steamboat, or down at the trenched gravel bar in the mouth of Northrup, or back at the summit scabland that margins the coulee. The *ensemble* in every detail supports the cataract hypothesis. Mentally reviewing other features not in sight, he may leave the viewpoint, confident that the hypothesis has a sound foundation and is a well-knit structure. Yet the concept is so extraordinary that in a few hours doubt recurs. Somewhere must lurk an unrecognized weakness. Where is it?

If it exists, it probably lies in the hydraulics of the concept. The total time allowable for Grand Coulee excavation is very brief. As now interpreted, the coulee could function only when the Cordilleran ice sheet stood at or less than thirty-five miles of its maximum. Even though, without good field evidence, we introduce adequate Columbia Valley blockades by a Chelan or a Wenatchee Valley glacier when the Okanogan lobe of the Cordilleran ice sheet is not so functioning, we can hardly have more than half a dozen deflections of the glacial Columbia across the plateau. Each must be of relatively brief duration. Since the upper coulee is more than three times as long as Niagara Gorge, the rate of cataract retreat must have been far in excess of Niagara's. The floor area of upper Grand Coulee is about fifty square miles, and the average depth to rock bottom is more than 800 feet. Thus about eight cubic miles of rock have been removed. The water dealt with fresh rock, no atmospheric disintegration having prepared it for removal. Is it conceivable that this could be done in the time available, even under the conditions asked for in the hypothesis?

Perhaps the most puzzling feature of Grand Coulee excavation is the summit scabland. Like large butte-and-basin scabland areas that were not canyoned later, it appears to have developed under minimum depth and minimum gradient of glacial stream. The greatest spread of this type of scabland occurs on the broad flattish divides near the northern margin of the plateau. In the summit scabland of Grand Coulee, water depths greater than one hundred feet do not appear possible, and stream surface gradients before cataract trenching apparently did not exceed ten feet to the mile. If these figures are approximately correct, one may question the stream origin of these broad stretches of scabland; for it seems unreasonable to assume that the rock basins were cut by such streams, however much time be allowed. One may seek escape in the suggestion that glacial ice really is responsible or he may beg the question by believing that the basins are earlier forms of the basalt surface brought to light when glacial water removed the loess.

But if they are the product of glacial stream erosion, then turbulence of the glacial flood and intimate jointing of the basalt seem to lie immediately back of the remarkable plucking. Here one hesitates again; for where are turbulent streams over closely jointed rock doing any such work? May we not test the hypothesis by reference to present-day cloud-burst and dam-burst floods?

The temptation is strong, but the warning is clear. We do not know enough about great flood mechanics to make any conclusions valid. Our approach must still be made by way of the fluvial forms of the scabland. If they are of channel origin, hydraulic competency must be allowed the glacial streams, however much it may differ from that of stream floods under observation.

The time element in the development of Grand Coulee may be greatly extended if later study should show that moraine and outwash deposits in Columbia Valley below the Okanogan lobe once were thick enough to continue the deflection through Grand Coulee after the ice dam had disappeared. Such a drift dam, however, will have no bearing on the duration of the great flood.

By the rejected hypothesis that upper Grand Coulee was simultaneously deepened through its entire length the time problem, with only an ice barrier, becomes even more difficult. A preglacial route, enlarged by the glacial discharge, is needed for this view. As indicated, such a preglacial valley seems forbidden by the field evidence.

CHAPTER V

UTILIZATION OF THE GRAND COULEE

The rainfall of east-central Washington is so close to the minimum for dry farming that even wheat raising is a gamble. Local irrigation proves the extraordinary fertility of the soil, but the region lies high above its only large source of water and has long seemed fated to remain a marginal agricultural province cursed by successive failures of its one possible crop. It is now proposed to reëstablish the ancient waterway through the great trench of the Grand Coulee. A mere trickle it will be, compared with the river of glacial times. Reinforced concrete will replace glacial ice; and a part, at least, of the west-flowing Columbia will again be detoured southward.

This irrigation scheme to utilize upper Grand Coulee as a conduit between a dam-retained lake in Columbia Valley north of the plateau and the dry but fertile soils south of the big monocline would not have been proposed had the coulee been a little less in depth. The coulee floor at the head is somewhat more than 500 feet above Columbia River, and a dam of this height across the river is of course impracticable. For one thing, it would pond the river as far upstream as Revelstoke, British Columbia, more than 300 miles by valley above the dam. The man-made obstruction to replace nature's successful blockade of the Pleistocene is planned to rise about 200 feet, less than halfway from river surface to coulee floor. The pond thus formed would extend only to Kettle Falls, 100 miles upstream, flooding no power sites of the future, no territory outside of Washington, and very little arable land. Through the remaining vertical distance the diversion water is to be lifted by giant pumps, power for which will be supplied by the fall at the dam.

The upper coulee floor has no continuous gradient. Rock bottom is exposed at each end, lying at almost the same altitude; but throughout its length large areas of the gorge floor lie below the altitude of the two exposed rock floors. These features essentially forbid a canal along the floor. Instead, a long lake will be made, its capacity increased by a low accessory dam on rock bottom at either end. The lake will serve as a gravity reservoir, and the main canal will head at the south end of the old cataract gorge.

No storage above the dam is necessary for the project, even at its maximum development. The high water of the Columbia River comes during the growing season, and only the flood excess over winter minimum will be needed for both irrigation and power for the lift into the coulee. The basic or minimum flow of the river may be utilized for commercial power, about half a million continuous horse power over pumping needs being expected.

A unique feature of the Columbia Basin irrigation project is that valley bottom lands will play almost no part except as drainage lines for escaping water. Loessial interfluves of the plateau will constitute a large part of the irrigated land, and broad gravel deposits of the Grand Coulee river and other glacial streams will rank next. The glacial river channels, however, will afford excellent drainage and locally can be used for secondary reservoirs and canals.

The diverted waters will first be led to extensive gravel deposits south of Grand Coulee. Suitable laterals, descending with lesser gradients than did the glacial stream, will bring water to large loess-covered areas farther south which escaped the glacial deluge. A total of about one and a half million irrigated acres is visualized, though the initial development will be less.

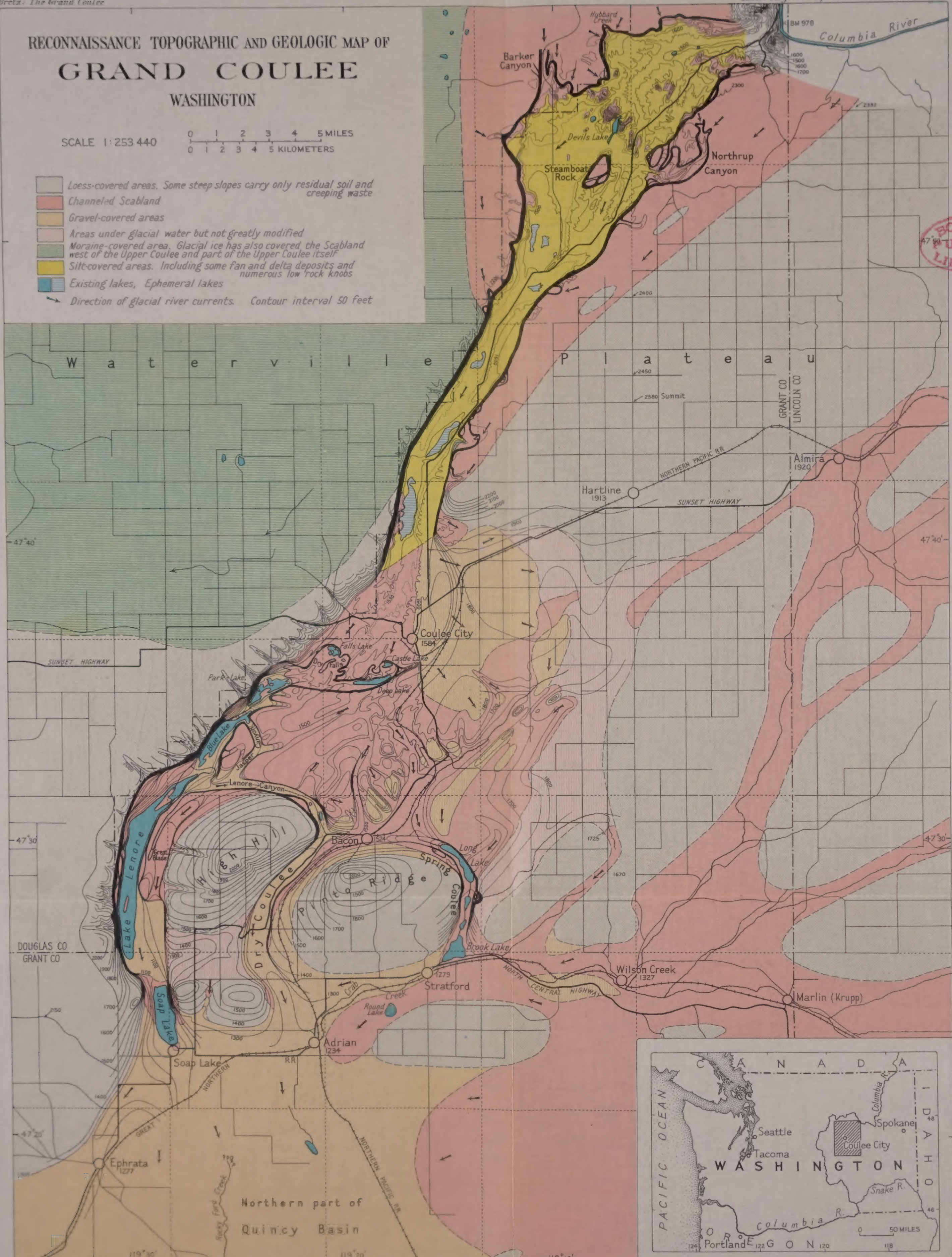
Suffering at one time apparently the maximum possible quantity of running water, the Columbia Plateau of Washington has been shifted through the vicissitudes of climatic change to its minimum. Man's ingenuity now promises it an optimum, delivered through the long cloudless summers. Wheat farming will give place, below the high-line ditch, to alfalfa growing and fruit raising. In the unclaimed or abandoned dry gravel soils sagebrush and bunch grass will vanish, and orchards will spread a summer greenery over the gray landscape. This result, if it comes to pass, will be because of the Grand Coulee, product of the greatest torrent of which the earth bears any record.

Conclusion

Lieutenant Symons, giving the region its first recorded geological examination, "went north through the coulee, its perpendicular walls forming a vista like some grand old ruined roofless hall, down which we travelled hour after hour." Its spectacular scenery has been often remarked by travelers since then.

The world, however, has unnumbered great canyons. Aside from their magnitude, they appeal to the intelligent observer because of the enormous cumulative result of changes wrought by a thread of water coursing the bottom. The appeal of Grand Coulee is different. The causal agent has vanished, and one's imagination must construct the process from the completed product alone. But the great gorge fairly bristles with sign manuals. Whatever they mean, they are *sui generis* among all canyons of comparable magnitude.

Grand Coulee asks of the visitor no sacrifice of his time or comfort. It is crossed by Yellowstone Trail at Coulee City, and automobile roads lead directly to almost every feature described herein. A few of its unparalleled characters require an additional hour or more of walking and climbing. It provides an adequate reward for anyone except the man to whom a cliff is but a cliff and all canyons are alike. And for "him who in the love of Nature holds communion with her visible forms" the majestic coulee tells a heroic tale of vanished power and glory far transcending that of Niagara and beggaring the leisurely story of the Yellowstone, the Yosemite, or even the Grand Canyon of the Colorado.



RECONNAISSANCE TOPOGRAPHIC AND GEOLOGIC MAP OF

GRAND COULEE

WASHINGTON

SCALE 1:253 440

- ▢ Loess-covered areas. Some steep slopes carry only residual soil and creeping waste
- 🟥 Channeled Scabland
- ▨ Gravel-covered areas
- ▢ Areas under glacial water but not greatly modified
- 🟩 Moraine-covered area. Glacial ice has also covered the Scabland west of the Upper Coulee and part of the Upper Coulee itself
- 🟨 Silt-covered areas. Including some fan and delta deposits and numerous low rock knobs
- 🟦 Existing lakes, Ephemeral lakes
- → Direction of glacial river currents. Contour interval 50 feet

0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
Columbia River
BM 978
Hubbard Creek
Barker Canyon
Devils Lake
Steamboat Rock
Northrup Canyon
W a t e r v i l l e P l a t e a u
Summit
GRANT CO
LINCOLN CO
NORTHERN PACIFIC RR
Almira
1920
Hartline
1913
SUNSET HIGHWAY
47°40'
47°50'
47°30'
47°20'
Coulee City
1584
Falls Lake
Castle Lake
Dry Falls
Park Lake
Deep Lake
Blue Lake
Jasper
Lenore Canyon
High Hill
Great Blade
Lake Lenore
Bacon
1524
Long Lake
Spring Coulee
Pinto Ridge
Dry Coulee
Brook Lake
Wilson Creek
1327
Marlin (Krupp)
NORTH CENTRAL HIGHWAY
DOUGLAS CO
GRANT CO
Soap Lake
Crab Creek
Round Lake
Stratford
1279
Adrian
1234
GREAT NORTHERN
RR
Ephrata
1277
Rocky Ford Creek
Northern part of Quincy Basin
NORTHERN PACIFIC RR
119°30'
119°20'
119°10'
C A N A D A
I D A H O
PACIFIC OCEAN
Seattle
Tacoma
Spokane
Coulee City
W A S H I N G T O N
Columbia R.
Snake R.
O R E G O N
Portland
124
122
120
118
48
46
0 50 MILES

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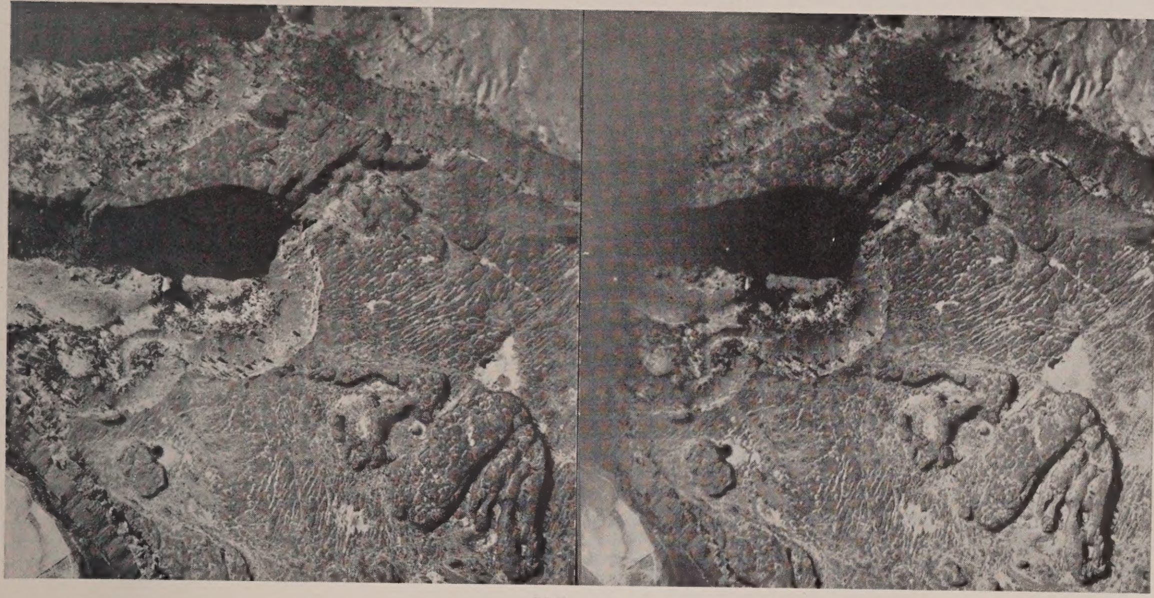

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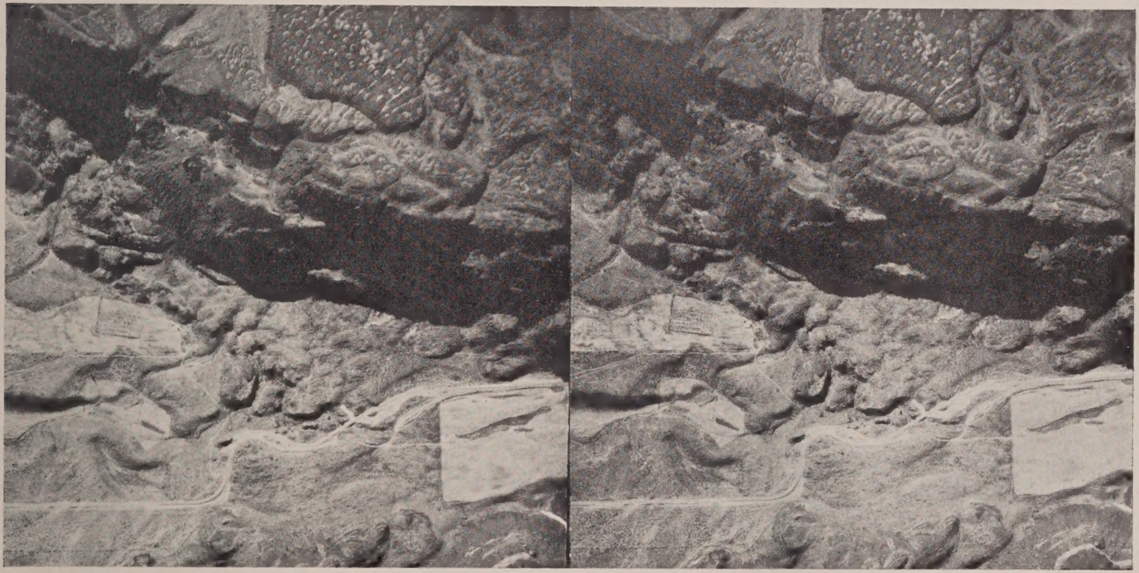

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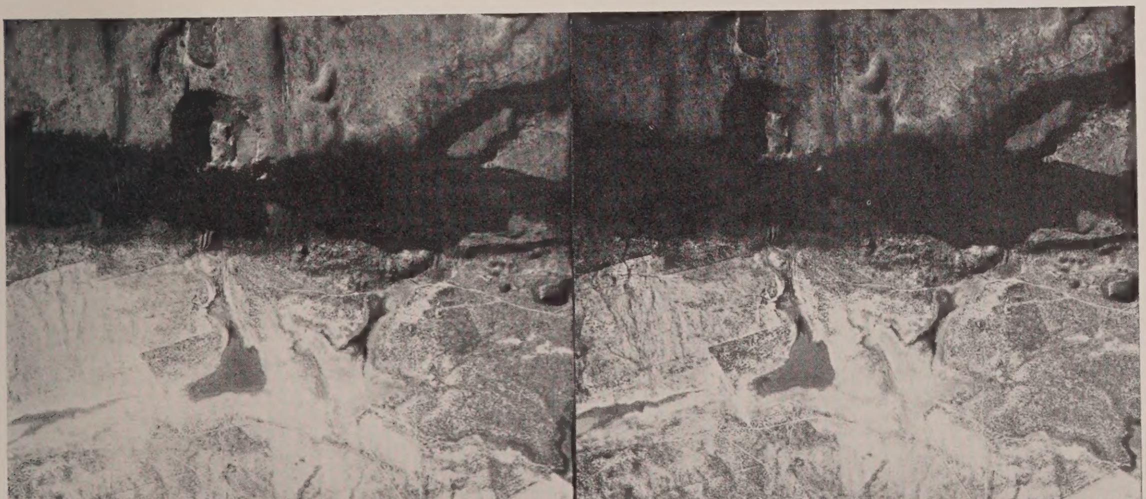
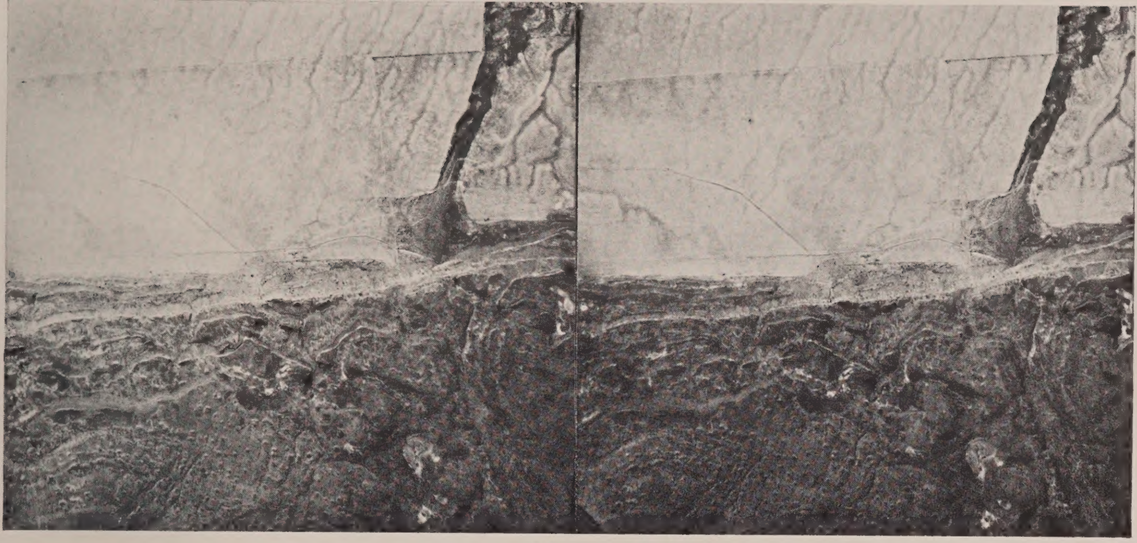


No. 3

Middle member of Northrup Canyon group, upper Grand Coulee. The westernmost member (upper left) cut completely back into Grand Coulee (upper right), the middle member lacked only a quarter of a mile of doing the same when it was abandoned through greater retreat of the main Steamboat Rock cataract. Note the channel floor scabland features on the summit flat, nearly a thousand feet above the coulee floor. Compare this view with the stereoscopic picture of Dry Falls (View 6). Note the difficulties of making this alcove a normal tributary to Grand Coulee.

Mouth of Barker Canyon, upper Grand Coulee. Note sculpturing of wall by plunging cataract water. Scabland on summit. A part of the opposite side of Barker Canyon shows in the extreme lower right. Grand Coulee floor occupies the lower left.

Detail of western wall, upper Grand Coulee. View west of Steamboat Rock. Two minor cataract niches hang on this wall. Scabland on summit. Silt-covered floor.



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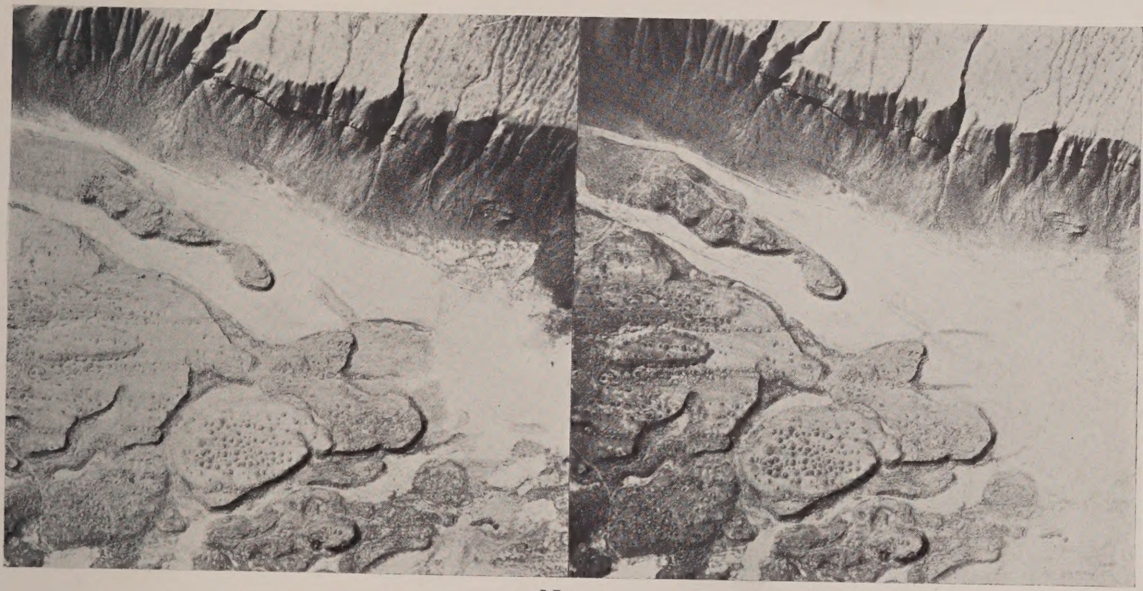

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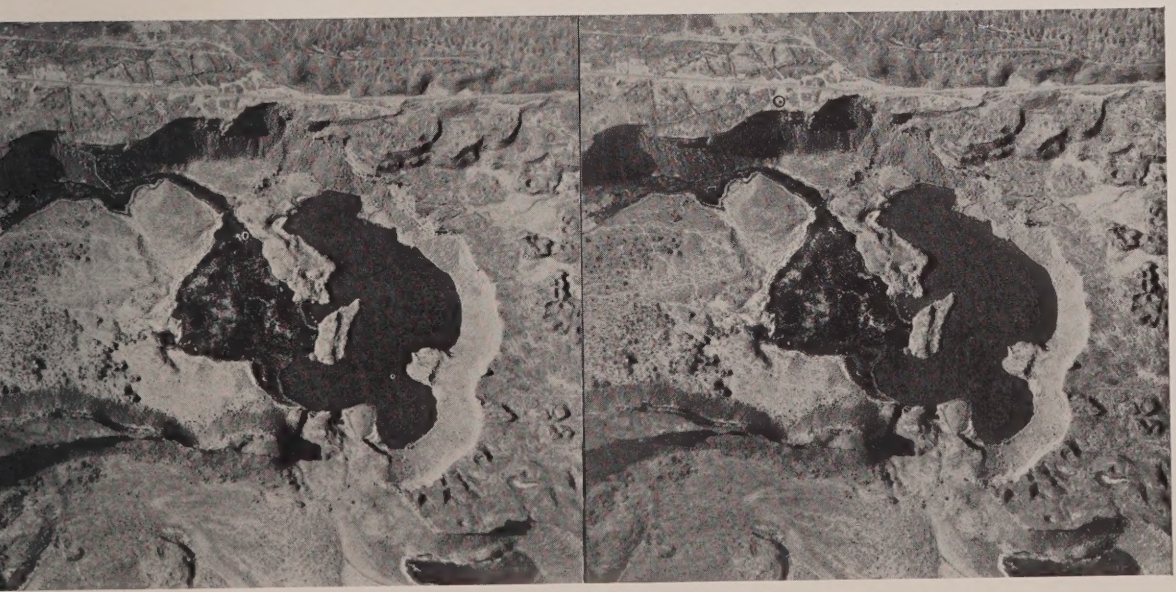
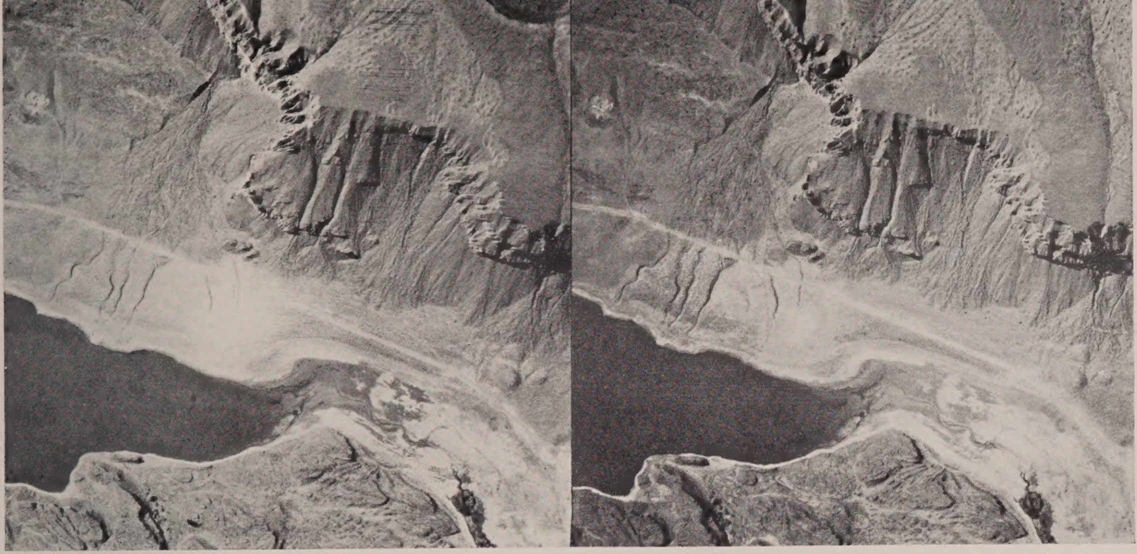


No. 6

Part of eastern wall of upper Grand Coulee. About five miles north of Coulee City. The scabland forms on the summit are superposed on preglacial gulches. Silt terrace at the foot.

Floor and western wall, south end of upper Grand Coulee. About five miles north of great cataract group. The floor is typical butte-and-basin scabland, the basins largely filled with silt. Normal gullies hang above the summit of the western wall.

Dry Falls State Park, westernmost member of great cataract group, head of lower Grand Coulee. The plunge basin lake has been partially filled with vegetation. Its rocky islands and peninsulas show several minor plunge basins. Small rock basins on the channel floor above the fall probably are plucked holes, not plunge basins. Part of the isolated blade between the two alcoves of Dry Falls shows at the left. Minor bars lie on the floor of the smaller alcove. Vista House, the viewpoint of most visitors, is marked by a circle.



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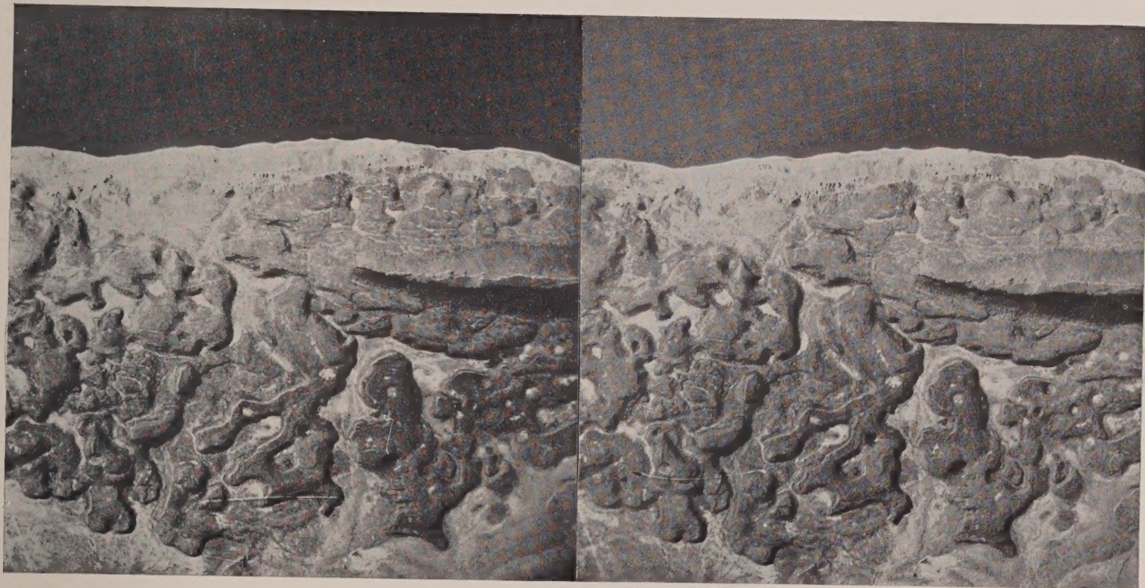

No. 8

Head of Lake Lenore, lower Grand Coulee. Butte-and-basin scabland. Normal gullies above top of western wall. Remnant of the monocline dips into the coulee. Scabland on lower edge of view is east of the monocline. A large gravel bar is on the left margin, between road and foot of talus.

Part of Great Blade, synclinal channel, and Lake Lenore, lower Grand Coulee. The numerous rock basins on the synclinal channel floor may be plunge pools of a cataract that has destroyed itself by recession. They are more probably plucked basins in the bed of the torrent.

No. 1—Middle member of Northrup Canyon group, upper Grand Coulee

No. 2—Mouth of Barker Canyon, upper Grand Coulee

No. 3—Detail of western wall, upper Grand Coulee

No. 4—Part of eastern wall of upper Grand Coulee

No. 5—Floor and western wall, south end of upper Grand Coulee

No. 6—Dry Falls State Park, westernmost member of great cataract group, head of lower Grand Coulee

No. 7—Head of Lake Lenore, lower Grand Coulee

No. 8—Part of Great Blade, synclinal channel, and Lake Lenore, lower Grand Coulee